ESSAYS

ON THE

ECONOMY OF FUEL, &c.

PRACTICAL AND DESCRIPTIVE
ESSAYS
ON THE
ECONOMY OF FUEL,
AND
MANAGEMENT OF HEAT.

ESSAY FIRST,
In Three Parts.

PART I.—On the effects of heat, means of measuring it, fuel, &c.

PART II.—On heating mills, dwelling-houses, and public buildings, by steam.

PART III.—On drying and heating by steam.

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PREFACE.

The favourable reception given by the public, to an *Essay on the Warming of Mills and other Buildings by Steam*, which I published in 1807 *, and the many additional facts on the subject, which, since that period, have been determined, and the further application of this agent to drying as well as heating, in various processes in calico-printing and other manufactures, have induced me to think of publishing an enlarged edition of that Essay.

Reflecting on this subject, and considering the materials I had collected on other practical applications of heat, it occurred to me, that I might extend my plan to a *series of Essays* on the *Economy of Fuel and Management of Heat.*

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* For an account of this Pamphlet, see Philosophical Magazine, Nicholson's Philosophical Journal, Monthly Magazine, and various other periodical publications for 1808.

In order to clear the way for these practical inquiries, it seemed proper, to give such a view of some of the principal laws which regulate the phenomena of heat, as would, by the help of references, enable the reader the better to understand the nature of the facts and observations which would occur in the subsequent parts of these inquiries. To this purpose, I have accordingly devoted the first part of this Essay.

Originally, I had no intention to make this introductory part so large as it now is, but in pursuing the subjects which it contains, it appeared to me, that to embrace the objects of my intention, it could not easily be made less. It would, perhaps, not conduce to my credit as a writer, were I to tell the trouble this part has cost me; and, after all my labour, I fear it will be thought by many, a mere compilation. But I was more anxious to make a useful than an elegant book, and, therefore, have attempted, in a small compass, to bring into view, all the practical knowledge that I could find on subjects, which I thought could be beneficial to a valuable class of men, whose time being otherwise fully occupied, have neither leisure, opportunity, nor inclination, to search into numerous, and often costly volumes. If I have succeeded in this intention, my labour has not been in vain. Nor will general readers, I trust, deem this part altogether unworthy their notice, having endeavoured in it, to give a concise view of the late important discoveries made by Professor Leslie and others, respecting heat.

The opportunities which I have had, of conversing and corresponding with several of these writers, as well as with other men of science, whose pursuits have been more immediately practical, I have endeavoured to turn to the advantage of the reader. In the "Additions and Corrections," I have studied to correct such errors or mistakes as have occurred in the course of this Essay.

The advantages which this island enjoys over other countries, from the abundance of coal, are too well known to require to be here enumerated. But in many other things we labour under much disadvantage, which should stimulate us to cherish this superiority which we enjoy over the nations on the Continent of Europe. The economy of fuel becomes a subject of increasing importance, from the increasing price of labour, which would require exertion to counteract its effects on our commerce and manufactures. Every attempt, therefore, to save fuel, merits attention; and the subject opens a wide and important field for investigation.

It is not the *saving* only of fuel which merits attention, but its *safe*, *easy*, and *healthful* application to the various purposes of life.

The recent destruction by fire, of St. James's Palace, and of the two largest Theatres in the kingdom, has directed much of the public attention to the rendering of buildings less subject to so dreadful a calamity. In this important respect, no means of heating buildings has yet been devised; so good as that by steam, and from its novelty, none is yet so partially known or understood. I have, therefore, been induced to make it the principal subject of this Essay.

It consists of Three Parts, the first of these I have already mentioned. The Second Part relates to the application of steam to the heating of buildings of various descriptions, such as dwelling-houses, manufactories, and public buildings. The Third Part treats of the application of this agent to *drying of goods*, as well as to further matters relative to heating. Its excellent effect in preserving brilliancy of colour, in drying goods, is there proved by strong facts;—a consideration of much importance in many of our manufactures.

I must crave the indulgence of the public, for any want of unity, and other imperfections, which will too readily appear in the whole of this Essay. I have to plead, that it was written at many different and distant intervals, occasioned by interruptions from professional engagements, as well as from other and more irksome causes, with a detail of which I shall not trouble the reader.

With regard to the subject of heating by steam, I beg leave here further to repeat the Preface to the Publication to which allusion is made at the beginning of this introduction.

"In a country like Britain, where manufactures are more generally collected and combined in large establishments, than dispersed through individual dwellings; the production and diffusion of the warmth necessary for the health and comfort of the workmen, as well as for the prosecution of the different processes, become objects of the first national importance.

"The excessive expense of insurance, arising from the combustible nature of the materials of the cotton manufacture in particular; the great difficulty of retrieving the injury resulting to a well established business, from the accidental destruction of machinery; and the frequent alarms from fire, in our powder-mills, arsenals, and dock-yards, furnish the strongest economical, as well as political recommendations, for the more general employment of steam for the purpose of warming buildings.

"The very limited degree in which steam has yet been applied to this purpose, might surprise us, did we not recollect, that the steam-engine itself, although known, perhaps, even before the time of the celebrated MARQUIS of WORCESTER, has only, within a very few years, by the ingenious improvements of MR. WATT, been extensively introduced. The frequent and various use of steam, to which MR. WATT's improvements have given rise, in different departments of manufacture, have furnished accidental results of great value, which are frequently little known to the merely scientific inquirer.

" The observations which the Author has been enabled to make, on various contrivances throughout the kingdom, for heating by steam, modified by his own experience, have led him to believe, that the following remarks on this important subject, would not be altogether undeserving the notice of the public.

" He, however, lays no claim to originality, nor does he pretend to give information to men of science, his object is merely to make such a collection of facts, as may be useful to those who wish to put in practice the warming of buildings by steam.

" In making this collection, he has been much indebted to the assistance of some friends, without the aid of whose ingenuity and experience, his readers would have had still more reason to lament its deficiency.

" Those who are most qualified to estimate the importance of such investigation,

[illegible]

can best appreciate their difficulty, and will, most readily and candidly, pardon the unavoidable imperfection of this attempt; the chief object of which, is less to satisfy curiosity, than to direct the attention of the public, to the farther prosecution of an inquiry, not less curious than useful."

I shall now proceed to give an account of the origin and progress of this application of steam.

An Account of the Origin and Progress of the Application of Steam, to the purpose of Heating Buildings.

In the Philosophical Transactions for the year 1745, Colonel William Cook suggests the idea of warming rooms by steam. But it does not appear that he ever attempted to reduce it to practice. And although Count Rumford, in the third number of the Journals of the Royal Institution, mentions, that "this scheme has frequently "been put in practice with success, in this "country, as well as on the Continent," I have not been able to learn, that any thing of importance was done, previously to the use of steam in warming cotton-mills *.

It is natural to suppose, that Mr. Watt's attention to other applications of steam, would lead him to the consideration of the particular subject of heating buildings. Such was indeed the case. The period at which he used steam for warming the room in which he commonly wrote, was 1784, or 5, probably the winter between these two years. The room was about 18 feet long, by 14 feet wide, and 8½ feet high; and the apparatus consisted of a box, or heater, made of two side-plates of tinned iron, about 3½ feet long, by 2½ wide, kept at the distance of an inch asunder, by means of stays, and joined round the edges by other tin-plates. This box was placed upon its edge, near the floor of the room, and furnished with a cock to let out the air, and with a pipe, proceeding from its

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* A patent for heating by steam was granted to John Hoyle, dated 7th July, 1791; and to Joseph Green, dated 9th December, 1793.

lower edge to a boiler in an under apartment, which pipe served to convey the steam, and return the water. The effect produced by this apparatus, was less than Mr. Watt had calculated, which, perhaps, may now be explained by Professor Leslie's experiments on the heat transmitted by polished surfaces.

Mr. Boulton heated a room in his manufactory by steam, soon after this time; but the very infirm state of his health at this moment, prevents me from obtaining accurate information concerning it*. He, however, heated his bath by steam, a few years later, I believe about the year 1789, which he continued to do from that period, until a very short time ago.

Towards the end of the year 1794, he assisted the late Marquis of Lansdown, to improve an apparatus, erected by a Mr. Green, for warming his library, by means of air heated by steam; but the use of it was afterwards abandoned, owing, I believe, to some defect in the pipes or joints. About a twelvemonth later, in the winter of 1795-6, Mr. Boulton directed the erection of a similar apparatus, for his friend Dr. Withering's library, which, in point of heating, answered perfectly; but the pipes being made of copper, and soft soldered in some places, the smell of the solder was rather unpleasant to the Doctor, who was then in an infirm state of health with diseased lungs. The apparatus was, in consequence, removed to Soho, where Mr. Boulton proposed erecting it in his own house, in which he was making alterations about this time, and had it in view, to heat every room in the house by steam. A boiler was put up for that purpose, in one of the cellars, but some circumstances occurred, to prevent his continuing the plan. The subject, however, underwent frequent discussions, and the different modes of effecting it, were amply considered by Messrs. Boulton and Watt, as was known to many of their friends, no secret having been made, either of calculations of surface, or of the modes of applying them.

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* *This was written previously to Mr. Boulton's death.*

About the end of the year 1799, Mr. Lee of Manchester, having a large increase of his cotton-mill in view, consulted with Messrs. Boulton and Watt, relative to the best mode of heating it by steam; and, in the course of the subsequent year, he erected his present apparatus of *cast-iron pipes*, acting also as supports to the floor, which answered perfectly, and was, both in point of the materials used, and of the construction adopted, as far as I know, the first of the kind. I may add, that though the construction has been frequently imitated by others, I have never heard of any material improvement having been made upon it. From that period, many apparatus were constructed by them, in some of which, applied to old buildings, the pipes were conducted horizontally through the rooms, with other variations of little importance.

It may not be improper here to add, the vats, &c. of the dye-house of Messrs. Wormauld & Gott, of Leeds, were heated by steam, under the direction of Messrs.

Boulton & Watt, in the year 1799. The apparatus was planned in August of that year, and set to work either in the course of it, or early in the succeeding one. The history of that establishment has been very incorrectly given, in the Journals of the Royal Institution, for 1801.

The merit of the first application of steam, to the heating of buildings in Scotland, belongs to Mr. Snodgrass. He introduced it * into the cotton-work, which Messrs. Dale & M'Intosh established on the banks of the Spey †.

Soon after this period, Mr. Houldsworth of Glasgow, used it with great success. His example has been followed by several other respectable cotton-spinners.

Steam was soon afterwards applied to warm buildings, appropriated to the purposes of calico-printing. Mr. Richard

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* In the year 1799, and, there is reason to think, without the knowledge of what had been done in England.

† See Philosophical Magazine for March, 1807.

Gillespie, in his calico-works at Anderston, was induced very early to use it in his warehouse for finished goods, and has since been gradually extending it through other parts of his works*. It has also been adopted by some calico-printers in England.

Messrs. W. Stirling & Sons are at present getting steam apparatus fitted up for their extensive calico-printing works at Cordale.

In Ireland, Messrs. Orr have introduced it at their works, at Stratford upon Slainy. It is also gradually finding its way into the cotton-mills in that kingdom.

Messrs. Oakley & Co. cabinet-makers, London, have heated their premises by steam; and Messrs. James Ballantyne & Co. have applied it to the heating of their printing-office in Edinburgh.

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[*] In the introduction to the Third Part of this Essay, there is a narrative respecting the application of steam to the purpose of *drying*.

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Part First.

ON THE EFFECTS OF HEAT, THE *MEANS OF MEASURING IT*, FUEL, &c.

SECTION I.

1. BEFORE proceeding to the more practical parts of the economy of fuel, in order to establish our inquiries on solid grounds, it will be proper here, to take a view of some of the principal laws which regulate the phenomena of heat.

The most eminent philosophers of the present age, are not yet agreed respecting the *nature* of heat, nor can any of them yet give to a plain inquirer a satisfactory answer to this simple question, What is heat? While some consider it as merely a *state* or *condition* of which all bodies are susceptible; others conceive that heat is a *material substance*—an elastic fluid, extremely subtile and active.

I shall not take up the reader's time, by attempting to investigate the merits of those opinions, since it is of no consequence to our present purpose, which of the parties is in the right.

But although we may not be able to comprehend the *nature* of heat, we may arrive at the knowledge of many of its *effects*, and so classify and arrange these, as to adapt them to many useful purposes in common life.

OF HEAT.

2. THE term *heat*, as used in common language, is ambiguous, being applied to express either a *certain sensation*, or the *external cause* which excites that sensation. It is in this last sense only, that we are at present to consider it; and to this meaning of the term *heat*, the authors of the New French Chemical Nomenclature, have given the definite name of *caloric* *.

3. " When all surrounding bodies are of one temperature, then the heat attached to them is in a quiescent state; the absolute quantities of heat in any two bodies, in this case, are not equal, whether we take

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* " The term *caloric* has been adopted in the New Nomenclature, to avoid that ambiguity and misconception which might, it is said, arise from employing the same term to express a substance, and the sensation produced by the action of that substance. By the same mode of reasoning, all the *substantives* should be changed, in any language that has similar *verbs*. But suppose the argument, for change, in the present instance, to have full force in some languages, it has little or none with regard to the English, which employs the word *warmth* to express the sensation occasioned by *heat*. I shall, however, use the terms heat and caloric indifferently."

Tilloch's Philosophical Magazine, vol. 8. p. 71.

the bodies of equal weights, or of equal bulks. Each kind of matter has its peculiar affinity for heat, by which it requires a certain portion of the fluid, in order to be in equilibrium with other bodies at a certain temperature [*]." Thus, when the heat of a room is increased, the various bodies contained in it will attract and retain different quantities of heat. This property seems to indicate the materiality of caloric, since, though in a quiescent state, it exists in bodies in different proportions, modified neither by their density nor form, but by some innate and peculiar force of attraction, resembling chemical affinity. To express this faculty, the term *capacity* for heat was invented, and employed by the British philosophers; the name *specific caloric* being used for the same purpose, by those on the Continent.

However various the capacities of bodies for heat may be, yet, in consequence of the perfect elasticity of this power, it will speedily acquire the same tension in them all; or, like a number of tubes of different magnitudes, but narrow apertures, plunged into the same vessel of water, it will soon stand in each at the same height or level, though the absolute quantity in them be very different. Now, it must evidently be a desirable object, with the philosopher, to obtain some means of estimating this tension, or height, or degree of temperature, as it is technically termed.

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[*] Dalton's Chemical Philosophy, p. 2.

Of Thermometers.

4. THE thermometer was invented early in the 17th century, but, like many other useful contrivances, its real author has never been ascertained. The first form of this instrument was the air thermometer. The air was confined in a tube by means of some coloured liquor, and the liquor rose or fell in the tube, accordingly as the air became expanded or condensed. It was found, however, to be very defective. The expansion of spirit of wine was next used, but still thermometers had a great defect; the scale did not commence at any *fixed*

point. While they laboured under this disadvantage, they could not be of general use.

The subject which next drew the attention of philosophers, was to obtain some *fixed unalterable points*, by which a determinate scale might be formed, so that all thermometers might be accurately adjusted to one standard. These important points, on which the accuracy and value of the thermometer depends, although previously discovered by Dr. Hooke [*], seem first to have been practically applied by Sir Isaac Newton. He chose, as fixed, those points at which water freezes and boils; the very points which the experiments of succeeding philosophers have determined to be the most fixed and convenient. Sir Isaac Newton used lintseed oil in his thermometer, which was constructed in 1701.

5. Oil, however, was found to have many imperfections. At length a different

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[*] Dr. Robert Hooke discovered the permanency of the temperature of freezing in 1664, and of boiling water in 1684.

fluid was proposed, by which thermometers could be made free from most of the defects alluded to. This fluid was mercury, and seems first to have occurred to Dr. Halley, about the end of the 17th century, but was not adopted by him, on account of its having less expansibility than the other fluids then in use for thermometers. The honour of this invention is commonly given to Fahrenheit of Amsterdam, who presented an account of it to the Royal Society of London, in 1724.

6. Fahrenheit's thermometer consists of a slender cylindrical tube, and a small bulb. To the side of the tube is annexed a scale which Fahrenheit divided into 600 equal parts, beginning with that of the severe cold which he had observed in Iceland, in 1709, or that produced by surrounding the bulb of the thermometer with a mixture of snow with sal-amoniac, or with sea-salt. The point at which mercury begins to boil, he made the other limit of his scale. By trials, he found that the mercury stood at 32° on his scale, when snow or

ice just begins to thaw, which was, therefore, called the *freezing point.* When the tube was immersed in boiling water, the mercury rose to 212°, which was, therefore, denominated the *boiling point*, and is just 180° above the freezing point.

7. But the present method of making these thermometers, is to immerse the bulb in melting ice or snow, and mark the place where the mercury stands with the number 32°, then immerge it in boiling water, and again mark the place where the mercury stands in the tube, which indicates the position of 212°. Dividing, therefore, the intermediate space into 180 equal parts, will give the scale of the thermometer, and which may afterwards be continued upward and downward at pleasure.

8. These fixed points are now universally chosen for adjusting thermometers to a scale, but it is well known that the point at which water boils is not invariable. It varies some degrees, according to the weight and temperature of the atmosphere.

9. In order, therefore, to insure uniformity in the construction of thermometers, it is now agreed, that the bulb of the tube be suspended in the steam when the water boils violently, the barometer* standing at 30 English inches, which is its mean height round London, and the temperature of the atmosphere 55° †.

10. Fahrenheit's thermometer is now universally used in this kingdom. *See Fig.* 1.

The centigrade thermometer, or that of France, since the Revolution, places Zero, or 0, at the freezing point, and divides the range between it and the boiling point into 100°. This has been long used in

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[*] I suppose the reader to be previously acquainted with the doctrine of the *pressure of the atmosphere*, and the construction of the *barometer*. If not, as it is necessary to the right understanding of the following parts of this Essay, I beg leave to refer to Gregory's Mechanics, vol. 2. p. 112, or almost any other of the elementary Treatises on Natural Philosophy.

[†] See the Report of the Committee for adjusting Thermometers. Philosophical Transactions, vol. LXVII.

Sweden, under the title of Celsius's thermometer. *See Fig.* 2.

11. Reaumur's thermometer, which was formerly used in France, divides the space between the freezing and the boiling of water, into 80 degrees, and places the Zero at the *freezing point. Fig.* 2.

12. Mr. Murray has suggested a scale which, he conceives, would be much more convenient than that of Fahrenheit. He uses, as fixed points, those of the freezing and boiling of mercury, and divides the intermediate space into one thousand parts, or degrees *. *See Fig.* 3.

13. The expansion which is observed in a mercurial thermometer, is, in reality, only the difference of expansions of mercury and of glass.

14. It has long been supposed, that the *equal* divisions on Fahrenheit's scale, did

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* Murray's Chemistry, vol. i. p. 153.

not point out the real equal increments (or degrees of equal increase) of temperature. This circumstance was not overlooked by Dr. Black, who illustrates it in the following manner: "If a string be stretched, by suspending a moderate weight to it, and we add one pound to that weight, we shall make it a little longer; but by adding a second pound, we shall not add as much more to the length of the string as the first pound added, nor will a third pound produce so much effect as the second pound. In like manner, we can imagine, that when a thermometer receives a series of equal additions to its heat, these may not produce equal increments of expansion; and, therefore, that equal increments of expansion may require for their production, increments of heat, very unequal among themselves. This question has been overlooked, or little attended to, by some of the principal writers on thermometers. It does not appear to have occurred to Dr. Boerhaave, and Dr. Martin gives very little attention to it. I began to attend to it, and made an experiment to decide it in the year 1760, and did not then know that others had thought of it; but I soon learned, that Boyle, Renaldini of Padua, Wolfius, Dr. Halley, Sir Isaac Newton, and Dr. Brook Taylor, had severally given their opinions or doubts concerning this question [*]."

The result, however, of Dr. Black's inquiry was, "that equal additions, or abstractions of heat, produced equal variations of bulk in the liquor of the thermometers employed by him, and, therefore, that the scale of expansion was also a scale of heat [†], or, at least, that there was but "*a little deviation from the exact proportion.*"

"M. De Luc," says Mr. Dalton, "found that in mixing equal *weights* of water, at the freezing and boiling temperatures, 32° and 212°, the mixture indicated nearly

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[*] Vide Black's Lectures, vol. i. p. 56 and 57.

[†] Black's Lectures, vol. i. Preface, p. xxxix.

119° of Fahrenheit's thermometer, but the numerical mean, or average, is 122°. If he had mixed *equal bulks* of water at 32° and 212°, he would have found a mean of 115°."

15. "It is not improbable, that the true mean temperature between 32° and 212°, may be as low as 110° of Fahrenheit*".

We are indebted to Mr. Dalton, for farther investigating this intricate subject, and he has formed a scale which, he conceives, will correspond with the increments of heat; and, as this is an important part of our subject, I shall here give some extracts with relation to it, from his late valuable publication.

16. "In the present imperfect mode of estimating temperature, the equable expansion of mercury is adopted as a scale for its measure. This cannot be correct, for two reasons: 1st, The mixture of water of

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* Dalton's Chemical Philosophy, p. 7.

different temperatures, is always *below* the mean by the mercurial thermometer; for instance, water of 32° and 212° being mixed, gives 119° by the thermometer; whereas, it appears, from the preceding remarks, that the temperature of such mixture ought to be found above the mean 120°. 2d, Mercury appears, by the most recent experiments, to expand by the same law as water, namely, as the square of the temperature from the point of greatest density. The apparently equal expansion of mercury, arises from our taking a small portion of the scale of expansion, and that at some distance from the freezing point of the liquid.

17. " From what has been remarked, it appears, that we have not yet any mode, easily practicable, for ascertaining what is the true mean between any two temperatures, as those of freezing and boiling water; nor any thermometer which can be considered as approximating nearly to accuracy.

18. " Heat is a very important agent in nature; it cannot be doubted, that so active a principle must be subject to general laws. If the phenomena indicate otherwise, it is because we do not take a sufficiently comprehensive view of them. Philosophers have sought, but in vain, for a body that should expand uniformly, or in arithmetical progression, by equal increments of heat; liquids have been tried, and found to expand unequally; all of them expanding more in the higher temperatures than in the lower, but no two exactly alike. Mercury has appeared to have the least variation, or approaches nearest to uniform expansion, and on that and other accounts, has been generally preferred, in the construction of thermometers.

19. " Some time ago, it occurred to me as probable, that water and mercury, notwithstanding their apparent diversity, actually expand by the same law, and that the quantity of expansion is as the square of the temperature, from their respective freezing points. Water very

nearly accords with this law, according to the present scale of temperature, and the little deviation observable, is exactly of the sort that ought to exist, from the known error of the equal division of the mercurial scale. By prosecuting this inquiry, I found that the mercurial and water scales, divided according to the principle just mentioned, would perfectly accord, as far as they were comparable, and that the law will probably extend to all other pure liquids, but not to heterogenous compounds, as liquid solutions of salts *."

20. "However, it now appears, that the force of steam, in contact with water, increases ACCURATELY in geometrical progression, to equal increments of temperature, provided those increments are measured by a thermometer of water or mercury, the scales of which are divided according to the above-mentioned law.

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* Dalton's Chemical Philosophy, p. 8—11.

21. "The force of steam having been found to vary by the above law, it was natural to expect that of air to do the same; for, air (meaning any permanently elastic fluid) and steam are essentially the same, differing only in certain modifications. Accordingly, it was found upon trial, that air expands in geometrical progression to equal increments of temperature, measured as above. Steam detached from water, by which it is rendered incapable of increase or diminution in quantity, was found, by Gay Lussac, to have the same quantity of expansion as the permanently elastic fluids. I had formerly conjectured that air expands as the *cube* of the temperature from absolute privation, as hinted in the essay above-mentioned; but I am now obliged to abandon that conjecture.

22. "The union of so many analogies, in favour of the preceding hypothesis of temperature, is almost sufficient to establish it; but one remarkable trait of temperature, derived from experiments on the heating and cooling of bodies, which does not ac-

cord with the received scale, and which, nevertheless, claims special consideration, is, that *a body in cooling loses heat in proportion to its excess of temperature above that of the cooling medium;* or that the temperature descends in geometrical progression in equal moments of time. Thus, if a body were 1000° above the medium; the times in cooling from 1000° to 100, from 100 to 10, and from 10 to 1°, ought all to be the same. This, though nearly, is not accurately true, if we adopt the common scale, as is well known; the times in the lower intervals of temperature are found longer than in the upper; but the new scale proposed, by shortening the lower degrees, and lengthening the higher, is found perfectly according to this remarkable law of heat.

23. "Temperature then will be found to have four most remarkable analogies to support it.

"1st. All pure homogenous liquids, as water and mercury, expand from the point of their congelation, or greatest density, a quantity always as the square of the temperature from that point.

" 2. The force of steam from pure liquids, as water, ether, &c. constitutes a geometrical progression to increments of temperature in arithmetical progression.

" 3. The expansion of permanent elastic fluids, is in geometrical progression to equal increments of temperature.

" 4. The refrigeration of bodies is in geometrical progression in equal increments of time.

" A mercurial thermometer graduated according to this principle, will differ from the ordinary one with equidifferential scale, by having its lower degrees smaller, and the upper ones larger; the mean between freezing and boiling water, or 122° on the new scale, will be found about 110° on the old one.—The following table exhibits the numerical calculations illustrative of the principles inculcated above *."

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* Dalton's Chemical Philosophy, p. 11—14.

TABLE.

24.

I.	II.	III.	IV.	V.
True equal intervals of temperature.	Common Fahrenheits scale; or preceding column corrected for expansion of glass	Expansion of air in geometrical progression. Ratio 1,0179.	Expansion of water as square of temperature.	Force of vapour of water in geometrical progression. Ratio 1,321. Inches of Mercury.
—175°	—40°—	692.—		
— 68°	—21.12	837.6		.012
— 58	—17.06	852.5		.016
— 48	—12.96	867.7		.022
— 38	— 8.52	883.3		.028
— 28	— 3.76	899.—		.088
— 18	1.34	915.2		.050
— 8	6.78	931.5		.066
2	12.63	948.2	16	.087
12	18.74	965.2	9	.115
22	25.21	982.4	4	.151
32	32°	1000	1	.200
42	39.3	1017.9	0	.264
52	47.—	1036.1	1	.348
62	55.—	1054.7	4	.461
72	63.3	1073.5	9	.609
82	72.—	1092.7	16	.804
92	81	1112.3	25	1.062
102	90.4	1132.2	36	1.40
112	100.1	1152.4	49	1.85
122	110.—	1173.1	64	2.45
132	120.1	1194.—	81	3.24
142	130.4	1215.4	100	4.27
152	141.1	1237.1	121	5.65
162	152.—	1259.2	144	7.47
172	163.2	1281.8	169	9.87
182	175.—	1304.7	196	13.02
192	186.9	1328.—	225	17.19
202	199.—	1351.8	256	22.70
212	212.—	1376.—	289	30.00
312		1643		485.—
412		1962		
512		2342		
612		2797		
712		3339		

Explanation of the Table.

25. Column I. contains the degrees of temperature, of which there are supposed to be 180, between freezing and boiling water, according to Fahrenheit. By comparing this column with the II. the correspondences of Mr. Dalton's new scale and the common one are perceived; the greatest difference between 32° and 212°, is observable at 122° of the new scale, which agrees with 110° of the old, the difference being 12°; but below 32° and above 212° the differences become more remarkable.

The first number in the column, —175° denotes the point at which mercury freezes, hitherto marked —40°.

By viewing column II. along with the I. the quantity of the supposed error in the common scale may be perceived; and any observations on the old thermometer may be reduced to the new. *See Fig.* 1.

Column II. contains the common Fahrenheit's scale.

Column III. contains a series of numbers in geometrical progression, representing the expansion of air, or elastic fluids.

Column IV. contains the squares of the arithmetical series, 1, 2, 3, &c. representing the expansion of water by equal intervals of temperature.

Column V. contains the force of aqueous vapours in contact with water, expressed in inches of mercury, at the respective temperatures.

26. On the construction hitherto described, the thermometer is necessarily very limited in its application. When made with alcohol, or spirit of wine, it may be said, indeed, to measure the greatest degrees of cold with which we are acquainted; but even the mercurial thermometer measures no higher than 400 degrees above boiling water, by Fahrenheit's scale, or about 250 degrees by Mr. Dalton's new scale, at which temperature mercury boils. This comes short of red

heat, and is far below the highest attainable temperature. To supply this deficiency, and to measure high temperatures, various methods have been proposed. The instruments thus applied to measure high temperatures, are usually named *pyrometers.* That which has come into most general use, was invented by the late Mr. Wedgewood; but even on this instrument there is still great room for improvement.

Wedgewood's pyrometer consists of cylindrical pieces of clay, composed in the manner of earthen ware, and slightly baked. When used, one of them is exposed in a crucible to the heat proposed to be measured, and after cooling, it is found to be contracted in proportion to the heat previously sustained; the quantity of contraction being measured, indicates the temperature.

The utility of this instrument, it was obvious, could be increased, by connecting it with the mercurial thermometer, and by ascertaining the proportional degrees of each. This was accordingly done by Mr. Wedgewood. Its scale commences at red heat, fully visible in day-light. Its whole range is divided into 240 equal degrees, each of which is calculated to be equal to 130° of Fahrenheit. The lowest, or 0, is found about 1077° of Fahrenheit (supposing the common scale continued above boiling mercury), and the highest 32277°.

In *Fig.* 4, is given a diagram, which may serve farther to illustrate the connection between the mercurial thermommeter, and that of Mr. Wedgewood.

The following table exhibits some of the more remarkable temperatures in the whole range of Reaumur, Fahrenheit, Celsius, and Wedgewood's thermometers.

27. *TABLE of the Degrees of different Thermometers omitting Fractions, at which some remarkable Chemical Phenomena occur.*

REAU.	FAHR.	CENT.	
54	90	68	Greatest artificial cold observed, produced by Mr. Walker.
44	66	55	Nitric acid freezes, *Fourcroy.*
36	50	44	Cold observed at Hudson's Bay, *M‘Nab.*
35	46	43	Ether freezes.
34	45	42	Ammonia exists in a liquid form.
32	39	39	Mercury freezes.
30	36	37	Sulphuric acid freezes, *Thomson*
28	31	35	Sulphurous acid liquid, *Monge.*
24	23	30	Cold observed at Glasgow on the surface of snow, 1780.
23	22	30	Acetous acid freezes.
20	14	25	Cold observed at Glasgow, 1780.
19	11	24	Two parts of alcohol and one of water freeze.
18	10	23	Cold observed on the snow at Kendal, 1791.
17	7	14	Brandy freezes.
14	0	18	Cold, produced by mixing equal parts of snow and muriate of soda.
7	16	9	Oil of turpentine freezes. Margueron did not freeze at —18 *Morelli.*
5	20	6	Strong wines freeze.
4	23	5	Fluoric acid freezes, *Priestly.* Oil of bergamot and cinnamon freezes, *Marg.*
3	25	4	Human blood freezes.
2	28	2.5	Vinegar freezes'
1	30	1.25	Milk freezes.
0	32	0	Oxymuriatic acid melts, *Thomson.* Water freezes.

REAU.	FAHR.	CENT.	
2	36	2.5	Olive oil freezes.
3	39	4	Heat of hedgehogs and marmots in a torpid state.
4	40	5	Oxymuriatic acid boils, *Thomson*. Equal parts of phosphorus and sulphur melt, *Pelletier*.
5	43	6	Phosphorus burns slowly.
6	45		Sulphuric acid, Sp. gr. 1.78, freezes, *Keir*.
10	55 to 66	12	Putrid fermentation, *Fourcroy*.
12	59	15	Vinous fermentation begins, *Fourcroy*.
14	64	17	Oil of anise freezes,
15	66 to 133	18	Animal putrefaction, 70 to panary fermentation.
16	68	20	Camphor evaporates, *Fourcroy*
18	74	23	Butter melts.
19	75	24	Summer heat at Edinburgh.
20	77	25	Vinous fermentation rapid, *Fourcroy*. Acetous ditto begins.
21	80	26	Phosphorus burns in oxygen gas. 104, *Goettling*.
21	75 to 80	26	Summer heat in England.
21	80	26	Heat of the ocean under the equator.
22	82	28	The adipocere of muscle melts.
25	88	31	Acetous fermentation ceases, *Fourcroy*. Phosphorus is ductile.
29	92 to 99	37	Heat of the human body.
28	97	36	Axunge melts, *Nicholson*.
28	97	36	Heat of a swarm of bees.
29	98	36	Ether boils.
30	99	37	Phosphorus melts, *Pelletier*.
31	100to103	39	Heat of domestic quadrupeds.
32	104	40	Resin of bile melts.
35	103to111	44	Heat of Birds.
33	107	41	Feverish heat.
	108		Hens hatch eggs.
34	109	42	Myrtle wax melts, *Cadet*.
35	111	44	Heat of the air near Senegal.

REAU.	FAHR.	CENT.	
36	112	45	Spermaceti melts, *Bostock.*
40	122	50	Phosphorus burns vividly, *Fourcroy.* 148, *Thomson.*
42	127	53	Tallow melts, *Nicholson.*
44	130	54	Ammonia is separated from water.
48	140	60	Ammonia boils, *Dalton.*
49	142	61	Bees-wax melts, *Irvine.*
50	145	63	Camphor sublimes, *Venturi.* Ambergris melts, *La Grange.*
55	155	79	Bleached wax melts, *Nicholson.*
59	165	74	Albumen coagulates. 156, *Black.*
61	170	77	Sulphur evaporates, *Kirwan.*
64	176	80	Alcohol boils. 174, *Black.*
90	235	116	Adipocere of biliary calculi melts, *Fourcroy.*
80	212	100	Water and volatile oils boil. Bismuth 5 parts, tin 3, and lead 2, melt.
83	219	104	Phosphorus begins to distil, *Pelletier.*
88	230	110	Muriate of lime boils, *Dalton.*
89	234	111	Sulphur melts, *Hope.* 212°, *Fourcroy.* 185°, *Kirwan.*
93	242	116	Nitrous acid boils.
96	248	120	Nitric acid boils.
103	264	130	Air breathed by the human species with tolerable ease, *Phil. Transac. vol.* 65.
112	283	140	White oxide of arsenic sublimes. Alloy of equal parts of tin and bismuth melts.
120	303	150	Sulphur burns slowly, and camphor melts, *Venturi.*
134	334	168	Alloys, tin 3 and lead 2, and tin 2 and bismuth 1, melt.
182	442	227	Tin melts, *Crichton.* 413, *Irvine.*
190	460	238	Tin 1, and lead 4, melt.
197	476	248	Bismuth melts, *Irvine.*
226	540	282	Arsenic sublimes.
232	554	290	Phosphorus boils, *Pelletier.*

REAU.	FAHR.	CENT.	WED.	
235	560	294		Oil of turpentine boils.
248	590	310		Sulphuric acid boils, *Dalton.* 546, *Black.* 540, *Berg.*
252	600	315		Lintseed oil boils. Sulphur sublimes, *Davy.* 570, *Thom.*
258	612	325		Lead melts, *Crichton.* 594, *Irvine.* 585, *Secundat.* 540, *Newton.*
269	635	335		Lowest ignition of iron in the dark.
279	660	350		Mercury boils, *Dalton.* 644, *Secundat.* 600, *Black.*
297	700	371		Zinc melts.
315	750	384		Iron bright red in the dark.
341	800	427		Hydrogen gas burns. 1000, *Thomson.*
342	802	428		Charcoal burn, *Thomson.*
345	809	432		Antimony melts.
380	884	475		Iron red in the twilight.
448	1050	560		Iron red-hot in a common fire.
462	1077	577	0	Red heat in day light.
564	1300	705	1.7	Azotic gas burns.
737	1807	986	6	Enamel colours burn.
1451	2897	1814	14	Diamond burns. 1, *Sir G. M‘Kenzie.* 5000, Morveau.
1678	3807	2100	21	Brass melts.
2024	4587	2530	27	Copper melts.
2082	4717	2602	28	Silver melts.
2130	4847	2700	29	Settling heat of plate glass.
2313	5237	2780	32	Gold melts.
2880	6507	3580	40	Delft ware fired.

REAU.	FAHR.	CENT.	WED.	
3750	8480	4680	57	Working heat of plate glass.
4450	10177	5610	70	Flint glass furnace.
5370	12257	6770	86	Cream coloured stone ware fired.
5664	12777	7080	90	Welding heat of iron least.
5800	13267	7330	94	Worcester china vitrified.
5953	13427	7441	95	Welding heat of iron greatest.
6270	14337	7850	62	Stone ware fired.
6520	14727	8150	105	Chelsea china vitrified.
6925	15637	8650	112	Derby china.
7025	15897	8770	114	Flint glass furnace greatest heat.
7100	16007	8880	121	Bow china vitrified.
			123	Equal parts of chalk and clay melt.
7460	16807	9320	124	Plate glass furnace strongest heat.
7650	17327	9600	125	Smith's forge.
7975	17977	9850	130	Cobalt melts. Cast iron melts.
8250	18627	10320	135	Bristol china no vitrification at
9131	20577	11414	150	Nickel melts. Hessian crucible melted.
9325	21097	11680	154	Soft iron nails melted with the crucible.
9602	21637	12001	158	Iron melts.
9708	21877	12136	160	Manganese melts. Air furnace.
10286	23177	12857	170	Platinium, tungsten, molybdenum, uranium, and titanium, melt.
11100	25127	13900	185	Greatest heat observed.
14331	32277	16802	240	Extremity of wedgewood's scale.

N. B. As many of these higher numbers were calculated from Wedgewood's, by the sliding rule, the two or three first figures only can be depended upon as correct. They will be found, however, to be sufficiently accurate for most purposes.

For more full information respecting various constructions of thermometers and pyrometers, I beg leave to refer to Mr. Murray's System of Chemistry, vol. 1st. I shall, however, when I come to speak of Mr. Leslie's experiments, give an account of his differential thermometer.

SECTION II.

Of Expansion.

28. Expansion of bodies is an important effect of heat. Solids are least expanded, liquids more, and elastic fluids most of all. The law of expansion of all permanently elastic fluids, has already been noticed (Art. 23.), it remains now to notice liquid and solid bodies.

29. Every body receiving heat, with a few exceptions, when accurately measured, is found to be enlarged, or expanded.

30. It may be proper to take notice of some of the exceptions to this law,—that bodies are expanded by heat. The most general exception is, that increase of bulk which takes place in several substances in changing from the fluid to the solid state. This is remarkably the case with water, the expansion of which, in freezing, is capable of overcoming a very great resistance, as was proved by Mr. Boyle, by the Floren-

tine academicians, and, more lately, by Major Williams. In one of his experiments, by the expansive force of freezing, an iron plug, weighing 2⅝ lbs. was projected to a distance of 415 feet, with a velocity of more than 20 feet in a second *.

Hence the bursting, during frost, of pipes for conveying water, the raising of pavement, the falling of parts of neglected buildings, the splitting of trees, rocks, &c.

31. But a phenomenon still more singular is exhibited by water, it expands not only in the instant in which it passes to the solid state, but before it reaches its freezing point. This singular phenomenon appears first to have been observed by Dr. Croune, towards the close of the 17th century. It was afterwards observed by Mairan; but De Luc seems to have been the first who attempted to investigate it with precision. Dr. Hope has since made experiments, from which he infers, that water obtains its maximum density at 40°,

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* Transactions of Royal Society of Edinburgh, vol. 2. p. 23.

that is, 8° warmer than at the freezing point, or 32°. Mr. Dalton has also investigated this subject, and from his experiments infers, " that *the greatest density of water, is at or near the 36° of the old scale*, and 37° or 38° of the new scale; and further, that the expansion of thin glass is nearly the same as that of iron, whilst that of stone ware is ⅔, and brown earthen ware ⅓ of the same *."

32. Permit me to direct the reader's attention to this very remarkable fact, that all bodies are condensed by cold without limitation, *water only excepted*, which we have just seen is, at its greatest density, at 36° of Fahrenheit's scale. This exception to one of those general laws of nature, is a striking proof of contrivance in the arrangement of the universe. Were it otherwise, all the fresh water within the polar circles must inevitably have been frozen to a very great depth in one winter, and a great portion of what is now the most temper-

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* Dalton's Chemical Philosophy, p. 34.

ate part of the globe, rendered a dreary waste.

To understand this, let us see what takes place in the freezing of a fresh water lake. When the cold air comes in contact with the particles at the surface, they are cooled, and becoming heavier descend until they are cooled down to the point of greatest density. Were this 32° then the whole water would continue this internal motion until it arrived at the freezing point, and being all equally cold, would become all at once solid ice.

But the water is heaviest at 36°, of course whenever it is all cooled down to that point, the internal motion ceases, and the surface becomes gradually colder until it arrive at the freezing point, when a thin body of ice forms a covering to the water, and particularly when snow is added, serves to protect it from the influence of the colder atmosphere.

For a fuller account of this instance of the beautiful economy of nature [*], as also what relates to the influence of salt water on the temperature of the globe, I may refer the reader to Count Rumford's seventh Essay.

33. According to Smeaton, " glass expands $\frac{1}{1200}$ in length for 180° of temperature, consequently it expands $\frac{1}{400}$ in bulk. But water expands $\frac{1}{21.5}$ or rather more than eighteen and one-half times as much [†]."

34. A knowledge of the comparative expansions of solids, is of much importance in the arts, and more particularly in the construction of time-pieces, which are much affected by the expansion of metals. This has led to a number of experiments on the subject; those of Mr. Ellicot [‡] appear to have been the first which were made with any degree of accuracy. He was followed in the same inquiry by Smeaton [||], Roy and Troughton and also by M. Berthoud [§].

[*] " Nature is but a name for an effect,
" Whose cause is God."—*Cowper.*

[†] Dalton, page 31, 32. [‡] Phil. Trans. vol. 39. [||] Phil. Trans. 48.

[§] Essai sur Horlogerie, 2d edit. Paris, 1786.

Although we perceive something like a relation subsisting between the expansion and fusibility of solids, those which are most fusible, as antimony, tin, lead, &c. expanding most, yet it must be confessed, that we know but very little with regard to the connection which subsists between the expansibility and other physical properties of solids.

No general law has hitherto been discovered, respecting the ratio of expansion of solid bodies; but for all practical purposes, we may adopt the notion of the equable expansion of solids. Glass, however, is an exception, for it has been found to expand in a ratio which increases with the temperature.

For measuring the longitudinal expansion of solids, various instruments, or pyrometers, have been invented, accounts of which may be found in most books, on natural philosophy. "The longitudinal expansion being found, that of the bulk may be derived from it, and will be three times as much. Thus, if a bar of 1000 expand to 1001 by a certain temperature, then a 1000 cubic inches of the same, will become 1003 by the same temperature *."

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* Dalton's Chem. Phil. p. 43, 44.

35. *TABLE of EXPANSIONS, for* 180° *of Fahrenheit*[*].

Solids.	*in Length.*	*in Bulk.*	
Earthen ware.			Wedgewood says, that earthen ware made porous by charcoal, expanded only one-third as much as when solid.
Brown earthen ware.	.000416	.0012	Dalton.
Stone ware.	.000208	.0012	Do.
Wood.			Much less than glass. Rittenhouse.
Glass rods and tubes.	.000208	.0025	Dalton.
—— bulbs thin.	.001234	.0037	Do.
—— tubes.	00077615	.002330	Roy.—Phil. Trans. 1785. He had before found a glass tube expand four times as much as a rod.
	50083333	.002502	Smeaton, Philosoph. Transac. 1754.
Glass rod.	00080787	.002426	Roy, the same glass as the tube.
Deal.			Roy, 1777, as glass.
Platina.	.000856	.002570	Borda.
Platina and glass.	.0011	.0033	Berthoud.
Regulus of antimony.	.001083	.003253	Smeaton.
Cast-iron prism.	.0011094	.003332	Roy.
Cast-iron.	.0011111	.003337	Lavoisier.
Steel rod.	.0011447	.003438	Roy.
Blistered Steel.	.001125	.003379	Phil. Trans. 1795, 428.
————	.001150	.003454	Smeaton.
Steel.	.0011574	.003476	Lavoisier.
Hard Steel.	.001225	.003679	Smeaton.
Annealed Steel.	.00122	.00367	Musschenbroek.
Tempered Steel.	.00137	.00411	Musschenbroek.

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[*] See Dalton's Chem. Phil. p. 44. and Young's Nat. Phil. vol. 2. p. 390—391.

Solids.	*in Length.*	*in Bulk.*	
Iron.	.001156	.003472	Borda.
——	.001258	.003779	Smeaton.
Annealed Iron.	.00133	.00400	Musschenbroek.
Hammered Iron.	.00139	.00417	Musschenbroek.
Bismuth.	.001392	.004180	Smeaton.
Annealed gold.	.00146	.00438	Musschenbroek.
Gold.	·0015	.0045	Ellicot, by comparison.
Gold wire.	.00167	.00502	Musschenbroek.
Copper hammered.	.001700	.005109	Smeaton.
Copper.	.00191	.00573	Musschenbroek.
Brass.	.001783	.005359	Borda.
Brass scale, supposed from Hamburgh.	.0018554	.005576	Roy.
Cast Brass.	.001875	.005635	Smeaton.
English plate brass rod.	.0018928	.005689	Roy.
English plate brass trough.	.0018949	.005695	Roy.
Brass wire.	.001933	.005811	Smeaton.
Brass.	.00216	.00648	Musschenbroek.
Copper 8 tin 1.	.001817	.005461	Smeaton.
Silver.	.00189	.005681	Herbert.
——	.0021	.0063	Ellicott, by comparison.
——	.00212	.00636	Musschenbroek.
Brass 16 tin 1.	.001908	.005736	Smeaton.
Speculum metal.	.001933	.005811	Smeaton.
Spelter solder brass 2 zinc 1.	.002058	.006187	Smeaton.
Fine pewter.	.002283	.006866	Smeaton.
Grain tin.	.002483	.007469	Smeaton.
Tin.	.00284	.00852	Musschenbroek.
Soft solder, lead 2 tin 1.	.002508	.007545	Smeaton.
Zinc 8 tin 1 a little hammered.	.002692	.008095	Smeaton.
Lead.	.002867	.008625	Smeaton.
——	.00344	.01032	Musschenbroek.
Zinc.	.002942	.008850	Smeaton.
Zinc hammered out half an inch per foot.	.003011	.009061	Smeaton.

Liquids.

Expansion in Bulks.

Mercury,	$.0200 = \frac{1}{50}$
Water,	$.0466 = \frac{1}{21.3}$
Water saturated with salt,	$.0500 = \frac{1}{20}$
Sulphuric acid,	$.0600 = \frac{1}{17}$
Muriatic acid,	$.0600 = \frac{1}{17}$
Oil of turpentine,	$.0700 = \frac{1}{14}$
Ether,	$.0700 = \frac{1}{14}$
Fixed Oils,	$.0800 = \frac{1}{12.5}$
Alcohol,	$.0110 = \frac{1}{9}$
Nutric acid,	$.0110 = \frac{1}{9}$

SECTION III.

On the Specific Heat of Bodies.

36. It was already observed, (Art. 3.) that different bodies at the same temperature, and showing the same degree on the thermometer, really contain different quantities of heat.

This diversity of the quantity of heat contained in different bodies, is called *specific heat;* and, accordingly, tables of the specific heat of bodies, showing their comparative attractions for heat, have been formed in a similar manner with tables of specific gravity, which show the comparative weights of bodies of equal bulks.

Sometimes the specific heat of bodies is deduced from equal *weights*, and sometimes from equal *bulks*, but it seems to be most correct to deduce them from equal *bulks* *.

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* See Dalton's Chemical Philosophy, p. 2.

Not being susceptible of measurement by the thermometer, different modes have been contrived for estimating it.

Lavoisier and Laplace used an ingenious contrivance called a calomiter, for investigating the specific heat of bodies. It was calculated to show the quantity of ice, which any body heated to a given temperature could melt; but, however ingenious in its construction, this instrument has not been found in practice to be sufficiently accurate.

Meyer attempted to find the specific heats of dried woods, by observing the times which equal volumes were in cooling. These *times*, he considered as proportionate to the capacities, or specific heats *bulk for bulk*, and when the *times* were divided by the specific gravities, the quotients represented the capacities of equal weights. This method was applied by Mr. Leslie to liquids, and has been approved of, and followed by Mr. Dalton.

37. The important fact of the absorption of heat, during the conversion of ice into water, appears to have been first observed, separately and unknown to each other, by De Luc, Black, and Wilkie, about the year 1755. On this experiment, Dr. Black principally founded his doctrine of *latent heat*. Dr. Irvine and Dr. Crawford, explained the circumstances somewhat differently, by the theory of a change of *capacity* for heat. Dr. Black's theory led to very vague, indistinct, and inaccurate notions on the subject; nor was the word *capacity* well chosen. The term *specific heat*, is that which is more approved by later writers, particularly Dalton and Leslie *.

38. By the method already mentioned, (Art. 38.) making proper allowance for the containing glass vessels, Mr. Dalton made his experiments on the specific heats of various bodies, the results of which will be found in the following Table. It will be sufficient to illucidate the use of

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* See Dalton's Chem. Phil.—Leslie's Inquiry, p. 529, also Mr. Tilloch's paper, Phil. Mag. 1808, p. 70.

the table, to give water and mercury as examples.

"If the whole quantity of heat in a measure of water of a certain temperature be denoted by 1, that in the same measure of mercury will be denoted by .5 nearly: hence the specific heats of water, and mercury, *of equal bulks*, may be signified by 1 and .5 respectively.

"If the specific heats, be taken from *equal weights* of the two liquids; then they will be denoted by 1 and .04 nearly, because we have to divide .5 by 13.6, the specific gravity of mercury *."

Mr. Dalton has discovered that water increases in its capacity for heat with the increase of temperature, and infers, that as much heat is necessary to raise water 5° in the lower part of Fahrenheit's scale, as is required to raise it 7° in the higher, and 6° in the middle.

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* Dalton, p. 47.

39. *TABLE of Specific Heats.*

GASES.	*Equal Weights.*	*Equal Bulks.*
Hydrogen	21.40*	.002
Oxygen	4.75*	.006
Common air	1.79*	.002
Carbonic acid	1.05*	.002
Azotic	.79*	.001
Aqueous vapour	1.55*	.001
LIQUIDS.		
Water	1.00	1.00
Arterial blood	1.03*	
Milk (1.026)	.98	1.00
Carbonat. of ammonia (1.035)	.95	.98
Carbonat. of pot-ash (1.30)	.75	.98
Solut. of ammonia (.948)	1.03	.98
Common vinegar (1.02)	.92	.94
Venous blood	.89*	
Solut. of common salt (1.197)	.78	.93
Solut. of sugar (1.17)	.77	.90
Nitric acid (1.20)	.76	.96
Nitric acid (1.30)	.68	.88
Nitric acid (1.36)	.63	.85
Nitrate of lime (1.40)	.62	.87
Sulphuric acid and water, equal bulks	.52	.80
Muriatic acid (1.153)	.60	.70
Acetic acid (1.056)	.66	.70
Sulphuric acid (1.844)	.35	.65
Alcohol (.85)	.76	.65
Ditto (.817)	.70	.57
Sulphuric ether (.76)	.66	.50
Spermaceti oil (.87)	.52	.45
Mercury	.04	.55

SOLIDS.	*Equal Weights.*	*Equal Bulks.*
Ice	.90	.83
Dried woods, and other vegetable substances from .45 to	.65	
Quicklime	.30	
Pit-coal (1.27)	.28	.36
Charcoal	.26*	
Chalk	.27	.67
Hydrat. lime	.25	
Flint glass (2.87)	.19	.55
Muriate of soda	.23	
Sulphur	.19	
Iron	.13	1.00
Brass	.11	.97
Copper	.11	.98
Nickel	.10	.78
Zinc	.10	.69
Silver	.08	.84
Tin	.07	.51
Antimony	.06	.40
Gold	.05	.97
Lead	.04	.45
Bismuth	.04	.40
Oxides of the metals surpass the metals themselves, according to Crawford.		

Remarks on the Table.

"The articles marked * are from Crawford. Notwithstanding the ingenuity and address displayed in his experiments on the capacities of the elastic fluids, there is reason to believe his results are not very near approximations to the truth; we can never expect accuracy when it depends upon the observation of 1 or 2 tenths of a degree of temperature after a tedious and complicated process. Great merit is undoubtedly due to him for the attempt.—The difference between arterial and venous blood, on which he has founded the beautiful system of animal heat, is remarkable, and deserves further inquiry†." For some account of Dr. Crawford's theory here alluded to, see Thomson's Chemistry, vol. iv. p. 72,—also, Adam's Lect. on Nat. Phil. vol. i. p. 396. But those who wish fuller information, I would refer to Dr. Crawford's valuable "Experiments and observations on Animal Heat."

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† Dalton p. 63.

40. "Water appears to possess the greatest capacity for heat of any pure liquid yet known, whether it be compared with equal bulks or weights; indeed it may be doubted, whether any solid or liquid whatever contains more heat than an equal bulk of water of the same temperature. The great capacity of water, arises from the strong affinity which both its elements, hydrogen, and oxigen, have for heat. Hence it is that solutions of salts in water, contain generally less heat in a given volume than pure water: for salts increase the volume of water as well as the density, and having mostly a small capacity for heat, they enlarge the volume of the water more than proportional to the heat they contribute *."

41. It is of importance to obtain the exact specific heat of the elastic fluids, because it has an intimate connection with the phenomena of combustion, and of heat in general. Of these, Mr. Dalton has given a theory, upon the principles of

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* Dalton, p. 64.

which, he has calculated the following table, respecting which he says,

“ We shall have the specific heats, of the several elastic fluids, as in the following table. In order to compare them with that of water, we shall further assume the the specific heat of water, to that of steam, as 6 to 7, or as 1 to 1.166.”

42. “ *TABLE of the Specific Heats of Elastic Fluids.*

Hydrogen - - -	9.382	Olefiant gas - -	1.555
Azote - - - -	1.866	Nitric acid - - -	.491
Oxygen - - -	1.333	Carbonic oxide - -	.777
Atmos. air - - -	1.759	Sulph. hydrogen -	.583
Nitrous gas - - -	.777	Muriatic acid - - -	.424
Nitrous oxide - -	.549	Aqueous vapour -	1.166
Carbonic acid - -	.491	Ether. vapour - -	.848
Ammon. gas - -	1.555	Alcohol. vapour - -	.586
Carb. hydrogen - -	1333	Water - - - -	1.000

“ Let us now see how far these results will accord with experience. It is remarkable, that the heat of common air comes out nearly the same as Crawford found it by experiment; also hydrogen excells all the rest, as he determined, but oxygen is much lower, and azote higher. The principles of Crawford's doctrine of animal heat, and combustion, however are not at all affected with the change *,

43. The phenomenon of animal heat has from the earliest ages been the subject of philosphical discussion, but its cause seems not yet ascertained. Of this, there are various degrees, some animals preserving a heat of 100° or more in all temperatures of the atmosphere; others, particularly the more imperfect, keep only a few degrees warmer than the medium, with which they are surrounded. That of the human body is from 96° to 98°, and it is truely wonderful that it should remain nearly the same in all climates. Men have lived in cold greater than that at which mercury freezes, (which is at 39° below zero,) and in an atmosphere above the heat of boiling water. Mr. M'Nab observed cold at Hudson's Bay 50° below zero. While the human species have, with impunity, breathed air 264° †, none of the inferior animals, seem capable

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* Dalton, page 73, 74.

† See Phil. Tran. Vol. 65.

of sustaining this change of temperature, while to man has been given this wonderful power of enduring all the variety of climates, which his necessities, or desire of knowledge, could lead him to visit, (Art. 27.)

I hope the following quotations, relative to the power of animals to sustain heat, will be acceptable to the reader.

" Air has often been breathed by the human species, with impunity, at 264°. Tillet mentions its having been respired at 300; and Morantin, one instance, at 325°, and that for the space of five minutes. Sonnerat found fishes, existing in a hot spring at the Manillas at 158° *: and M. Humboldt and M. Bonpland, in travelling through the province of Quito, in South America, perceived other fishes thrown up alive, and apparently in health, from the bottom of a vulcano, in the course of its explosions along with water, and heated

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* He graduates by Reaumur's thermometer, and calculates the heat upon this at 69°.

vapour that raised the thermometer to 210°, being only two degrees short of the boiling point *."

"There are indeed numerous facts, all of which tend to confirm the statement of these intrepid travellers. Dogs have existed without apparent inconvenience, in a temperature of 236°, measured by Fahrenheit's thermometer; a heat exceeding that of boiling water, by 24°. A species of tœnia has been found alive in a boiled carp; the oven-girls in some part of Germany, have sustained a heat of 257° for a quarter of an hour; one girl supported it ten minutes, when augmented to 288° without inconvenience, and another, breathed in air, heated to 325° for five minutes †; the incombustible man, described by Dr. Sementini, of Naples, would receive boiling oil into his mouth, and bathe his fingers in fused lead without injury ‡; and, to come nearer home, Sir Joseph Banks, bore a

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* Anniversary oration delivered, March 8, 1808, before the Medical Society of London, by John Mason Good, F. R. S.

† Hist. Acad. Scienc. 1764.

‡ Phil. Mag. vol. xxxii.

heated room, at 211°, while Sir Charles Blagden, has himself given an account[*] of his sustaining the heat of 260° in the surrounding facticious atmosphere[†]."

44. Bodies by changing their state, also change their *specific heat.* By a change of state in bodies, is meant their successive passage from solidity to liquidity, and from this to elastic fluidity, and contrariwise. Thus water may be in the state of ice, of liquid, and of vapour, or steam.

A solid body, as ice, on becoming liquid, acquires a great specific heat, even though its bulk be diminished; and a liquid, as water, acquires a greater specific heat, on being converted into an elastic fluid.

It was already mentioned, (Art. 39.) that the absorption of heat, during the conversion of ice into water, was observed by philosophers, about the year 1755; and Dr. Crawford has shown, that by the laws of absorption and extrication of heat, resulting from the change of capacity, which takes place in the solid and fluid states of water, Divine Providence, has wisely guarded against various sudden vicissitudes of heat and cold upon the surface of the earth. A vast quantity of heat is extricated in freezing of large masses, which renders the process very slow, while the great absorption of heat from the atmosphere, in thawing, occupies much time, and prevents that terrible devastation, which otherwise would take place from torrents produced by the sudden dissolution of ice and snow.

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[*] Phil. Trans. vols. lxv. and lxviii.

[†] Eclectic Rev. March, 1809.

45. During the conversion of water into steam, a great quantity of heat is absorbed; in consequence of which, when steam is again converted into water, much heat is extricated.

Hence the water which results from condensation, forms an accurate comparative measure of the heat extricated from steam of the same density, and, for this purpose, it was applied in experiments made by Mr. Houldsworth*, in comparing the effects of steam-tubes of tin-plate with those of cast-iron. The subject of steam will be farther considered, after treating of Ebullition.

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* See Part II.

SECTION IV.

Of Combustion.

46. Modern chemists consider the sources of heat, which are under the control of art to be the following:—Solar rays, electricity and galvanism, condensation, mechanical action between solids, including friction and percussion, and chemical action, to which head combustion belongs *.

Our concern at present is with combustion, but before proceeding to that subject, I shall very shortly notice some of the other sources of heat.

47. It has been long known, that coloured bodies when exposed to the light of the SUN, have their temperature raised in proportion to the darkness of their colour. —The simple experiment of touching a white and a black stone exposed to the

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* Murray's Chemistry, vol. i. p. 450.

rays of the sun, would be sufficient to give any one an idea of this truth. To ascertain this point, experiments were made by Dr. Hooke, by Dr. Franklin, and since, with more precision, by Mr. Davy *.

48. The temperature produced by the direct action of the rays of the sun, seldom exceeds 120°, but when they are concentrated, they are capable of producing a temperature as great at least, as the most intense and violent fires †.

49. Condensation of volume, it is well known, produces heat. This fact was long ago observed in condensing air in the air-gun. A curious application of this principle was, a few years ago, invented in France, and is now coming into use in this country. I allude to an instrument for kindling fungus, used instead of the tinder-box. It is simply a condenser, which, by compressing the air into a very small space, by a single stroke of the piston, sets fire to the fungus.

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* Thomson's Chemistry, vol. i. page 419. † Ibid. page 416.

Mr. Dalton accounts for the decrease of temperature of the atmosphere as we ascend, by supposing that the natural *equilibrium of heat* is an equality in *quantity* rather than *temperature.* Air increases in its capacity for heat by rarefaction. The temperature must, therefore, be regulated by the density of each atom of air, in the same perpendicular column, being possessed of the same quantity of heat. Now, it is well known, that the density of the air becomes less as we ascend, and, of course, the heat also decreases *.

50. Mr. Dalton is likewise of opinion, that the heat produced by FRICTION and PERCUSSION of solid bodies, results, in both cases, from the same cause, viz. condensation of volume, in the same manner as the condensation of air and other bodies produces heat †. (See Art. 49.)

51. It was the opinion of Crawford, Lavoisier, and many other modern chemists,

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* Dalton's Chem. Phil. p. 123. † Dalton's Chemistry, p. 123—133.

that oxygenous gas was the sole or principal source of the light and heat produced by combustion. But Mr. Dalton has proved, that although this may be nearly the case with regard to charcoal and pit-coal, that it is not true with regard to other combustible bodies. He concludes, "that the heat, and probably the light also, evolved by combustion, must be conceived to be derived both from the oxygen and the combustible body, and that each contributes, for ought we know to the contrary, in proportion to its specific heat before the combustion."* (Art. 43.)

Fuel.

52. DR. BLACK considers the fuels commonly used, under five divisions:—"The first may comprehend the fluid inflammables; to the second we may refer peat or turf; to the third, charcoal of wood; to the fourth, pit-coal charred; and to the fifth, wood or pit-coal in a crude state, and capable of yielding a copious and bright flame.—

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* Dalton's Chem. Phil. p. 81—82.

53. "1*st*, *The fluid inflamables* are considered as distinct from the solid, on this account, that they are capable of burning upon a wick, and become in this way the most manageable sources of heat; though, on account of their price, they are never employed for producing it in great quantity, and are only used when a gentle degree, or a small quantity of heat is sufficient. The species which belong to this class, are spirit of wine and different oils."

54. "The second kind of fuel mentioned, *peat*, is so spongy, that compared with the more solid fuels, it is unfit to be employed for producing very strong heats. —It is too bulky for this.—We cannot put into a furnace, at a time, a quantity that corresponds with the quick consumption that must necessarily go on when the heat is violent. There is no doubt a great difference in this respect, among different kinds of this fuel; but this is the general character of it. However, when we desire to produce and keep up, by means of cheap fuel, an extremely mild gentle heat,

we can hardly use any thing better than peat. But it is best to have it previously charred, that is, scorched, or burned to black coal. The advantages gained by charring it, will be presently explained. When prepared for use in that manner, it is capable of being made to burn more slowly and gently, or will bear, without being extinguished altogether, a greater diminution of the quantity of air with which it is supplied, than any other of the solid fuels. Dr. Boerhaave found it extremely convenient and manageable in his *Furnus Studiosorum*.

55. " The next fuel in order, is the *charcoal of wood*. This is the chief fuel used by the chemists abroad, and has many good properties. It kindles quickly, emits few watery or other vapours while burning, and when consumed, leaves few ashes, and those very light. They are, therefore, easily blown away, so that the fire continues open, or pervious to the current of air which must pass through it to keep it burning. This sort of fuel

too, is capable of producing as intense a heat as can be obtained by any; but in those violent heats it is quickly consumed, and needs to be frequently supplied.

55. "*Fossil coals charred*, called *cinders or coaks*, have, in many respects, the same properties as charcoal of wood; as kindling more readily in furnaces, than when they are not charred, and not emitting watery or other gross smoke while they burn. This sort of charcoal is even greatly superior to the other in some properties. It is a much stronger fuel, or contains the inflamable matter in greater quantity, or in a more condensed state. It is, therefore, consumed much more slowly on all occasions, and particularly when employed for producing intense melting heats. The only inconveniences that attend it are, that when it consumes, it leaves much more ashes than the other *, and these much

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* I do not know that this is the case with the finest pit-coal. I have seen some of the finest Newcastle coals which did not leave one fiftieth part of their weight of ashes, and even these did not seem entirely consumed.

heavier too, which are, therefore, liable to collect in such quantity, as to obstruct the free passage of air through the fire; and farther, that when the heat is very intense, these ashes are disposed to melt or vitrify into a tenacious drossy substance, which clogs the grate, the sides of the furnace, and the vessels. This last inconvenience is only troublesome, however, when the heat required is very intense. In ordinary heats the ashes do not melt, and though they are more copious and heavy than those of charcoal of wood, they seldom choke up the fire considerably, unless the bars of the grate be too close together.

" This fuel, therefore, is preferable in most cases, to the charcoal of wood, on account of its burning much longer, or giving much more heat before it is consumed. *The heat produced by equal quantities, by weight of pit-coal, wood-charcoal, and wood itself, are nearly in the proportion of* 5, 4, *and* 3. The reason why both these kinds of charcoal are preferred, on most occasions, in experimental chemistry, to the crude wood and fossil-coal, from which they are produced, is, that the crude fuels are deprived, by charring, of a considerable quantity of water, and some other volatile principles, which are evaporated during the process of charring, in the form of sooty smoke or flame. These volatile parts, while they remain in the fuel, make it unfit (or less fit) for many purposes in chemistry. For, besides obstructing the vents with sooty matter, they require much heat to evaporate them, and, therefore, the heat of the furnace in which they are burned is much diminished, and wasted by every addition of fresh fuel, until the fresh fuel is completely inflamed, and restores the heat to its former strength. But these great and sudden variations of the heat of a furnace, are quite inconvenient in most chemical processes. In the greater number of chemical operations, therefore, it is much more convenient to use charred fuel, than the same fuel in its natural state.

57. " The last kind of fuel is *wood, or fossil coal* in their crude state, which it is proper to distinguish from the charcoals of the same substances. The difference consists in their giving a copious and bright flame, when plenty of air is admitted to them, in consequence of which they must be considered as fuels, very different from charcoal, and adapted to different purposes.

" I had occasion formerly to remark, when treating of inflamation, that flame is produced from those substances only, which are either totally volatile when heat is applied to them, or which contain a quantity of combustible matter that is volatile, or easily convertible into vapour by heat; and that flame is nothing else but this vapour set on fire, or which becomes inflamed as fast as it arises from the body which affords it.

" Of this nature, therefore, is the flame of wood and fossil coal, when they are burned in their crude state. These fuels contain a quantity of inflamable matter, that is volatile, and which, when a moderate and stifled heat is applied to them, evaporates in the form of oily and sooty vapours and smoke, and diminishes the heat instead of increasing it. But if they are exposed to a stronger heat, and air is freely admitted, the sooty vapours are suddenly set on fire, or become flame, and continue afterwards to burn as fast as they arise from the wood or coal, in consequence of which they produce a great heat.

" These flaming fuels, however, have their particular uses, for which the others are far less proper; for it is a fact, that flame, when produced in great quantity, and made to burn violently, by mixing it with a proper quantity of fresh air, by driving it on the subject, and throwing it into whirls and eddies, which mix the air with every part of the hot vapour, gives a most intense heat. This proceeds from the vaporous nature of flame, and the perfect miscibility of it with the air. As the immediate contact and action of air is necessary to the burning of every combustible body, so the air, when properly applied, acts with far greater advantage on flame, than on the solid and fixed inflammable bodies, for when air is applied to these last, it can only act on their surface or the particles of them that are outermost; whereas flame being a vapour or elastic fluid, the air by proper contrivances can be intimately mixed with it, and made to act on every part of it, external and internal at the same time.—The great power of flame, which is the consequence of this, does not appear when we try small quantities of it, and allow it to burn quietly, because the air is not intimately mixed with it, but acts only on the outside, and the quantity of burning matter in the surface of a small flame, is too small to produce much effect. But when flame is produced in large quantity, and is properly mixed and agitated with air, its power to heat bodies is immensely increased; it is, therefore, peculiarly proper for heating large quantities of matter to a violent degree, especially if the contact of solid fuel with such matter is inconvenient. Flaming fuel is used for this reason, in many operations performed on large quantities of metal or metallic minerals, in the making of glass, and in the baking or burning of all kinds of earthen ware. The potters kiln is a cylindrical cavity, filled from the bottom to the top with columns of ware. The only interstices are those that are left between the columns; and the flame, when produced in sufficient quantity, proves a torrent of liquid fire, constantly flowing up through the whole of those interstices, and heats the whole pile in an equal manner.

" Flaming fuel is also proper in many works or manufactories, in which much fuel is consumed, as in breweries, distilleries, and the like. In such works it is evidently worth while to contrive the furnaces, so that heat may be obtained from the volatile parts of the fuel, as well as from the fixed; for when this is done, less fuel serves the purpose than would otherwise be necessary. But this is little attended to, or ill understood, in many of those manufactories. It is not uncommon to see vast clouds of black smoke and vapour coming out of their vents.

"This happens in consequence of their throwing too large a quantity of crude fuel into the furnace at once. The heat is not sufficient to inflame it quickly, and the consequence is, a great loss of heat *."

58. I hope it will not be considered an improper digression, to mention a subject which has lately excited a good deal of the public attention; I allude to the light produced from the gas proceeding from the distillation of pit-coal. From the Philosophical Transactions, it appears that, as far back as the year 1735, it was known as a fact, that coal yields an inflamable gas, but its beneficial application seems to have been reserved for Mr. Murdoch, in the year 1792. The most extensive cot-

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* Black's Lectures, vol. i. pages 312—316.

ton-mill in the kingdom, has been, for several years, lighted up with the gas from coal. The following extract from a periodical work of extensive circulation *, as giving a summary view of this subject, and as containing some valuable facts respecting fuel, I trust will be acceptable to the reader. But those who wish to pursue the subject, I would refer to the work alluded to, as well as to Mr. Murdoch's "Account of the Application of Gas from Coal to Economical Purposes," published in the Philosophical Transactions for 1808, and reprinted in Nicholson's Philosophical Journal, the Philosophical Magazine, and the Monthly Magazine for the same year.

"Pit-coal exists in this island in strata, which, as far as concerns the hundredth generation after us, may be pronounced inexhaustible; and is so admirably adapted, both for domestic purposes and the uses of the arts, that it is justly regarded as a

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* Edinburgh Review, vol. xiii. page 478.

most essential constituent of our national wealth. When exposed to heat, as we see it every day in our grates, it is manifestly composed of a fixed base of carbonaceous matter, and a variety of evaporable substances, which are driven off in the form of smoke and flame. But, instead of being consumed in this open way, the coal may be distilled, and these evaporable matters collected in proper vessels, and examined. They are then found to contain, besides a considerable quantity of matter, which is condensed by cold into tar and alkaline liquor, an invisible elastic fluid, or gas, which no cold nor affusion of water can condense or absorb. It is a compound of two highly inflamable gases, which chemists call the light hydrocarbonate, and the heavy hydrocarbonate, or olefiant gas; and this mixture burns with a very brilliant and beautiful light. It is this gas which furnishes the flame in our common fires*;

" * There are, in fact, according to Mr. Davy, three inflamable gases given out in our fires;—the two we have mentioned, and the gaseous oxide of carbon, which is known by its blue flame. They are all distinctly perceptible; the light hydrocarbonate forms the main body of the flame; the olefiant appears in brilliant jets; and the gaseous but its beauty is there impaired by the unavoidable alloy of smoky vapour. A separation, however, may be effected by the distilling process, which leaves the pure aerial fluid such as we have described. All the new plans for lighting with coal-gas, proceed upon the principle of purifying this fluid, collecting it in reservoirs, and distributing it in tubes. From the furnace where the coal is distilled, a main pipe may convey *all* the evaporable matter into a large reservoir or gasometer, where, by various means—chiefly, we believe, by washing with water, it may be freed from impurities, and propagated through the tubes in every direction by its own elasticity. If nothing confine it, it will issue from the extremities in an equable flow, but still invisible, till a lighted taper be applied; when it bursts into flame, and continues to burn as long as the gas is supplied. Mr. Accum found, by a comparison of shadows, in the manner sug-

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oxide is occasionally seen near the root of the flame, or in contact with the coal. It is possible that a small portion of this oxide may mix with prepared gas.

gested by Count Rumford, that the light of a gas flame is to that of an equal-sized flame of a candle or lamp as 3 to 1 *; or, in other words, that to light up a certain space, one gas flame will give as much light as three candles burning with a flame of equal size. The products of the combustion are, in both cases, the same,—water and carbonic acid gas; but with this material difference, that candles frequently, and lamps always, give out a quantity of smoke and soot; whereas the combustion of the gas is perfect, and leaves no sensible residuum,—nothing that can soil the most delicate white. Its effects on the air of a room are, therefore, less insalubrious than those of a candle, since the only noxious substance it yields is carbonic acid gas; and this it produces in smaller quantity than our common lights. From the in-

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" * We should have suspected the proportion was over-rated, had not the same accurate experimenters assured us, ' that 500 cubic inches of gas, burnt from the orifice of a jet, so as to produce a flame equal in size to that of an ordinary candle, consumed 1076 cubic inches of oxygen gas in the same time that a candle, kept burning in the best possible manner, consumed only 279; and we know, that the intensity of any artificial light depends on the rapidity with which oxygen is absorbed.'—See Appendix to Report of the Committee, &c.

flamable properties of the gas, explosions, bursting of tubes, and other dangers might be apprehended. But there is no ground for such fears. On the contrary, nothing can be more simple or easy in the management. The gas may be confined by a stop-cock with perfect safety, and issued as occasion requires. When it is exhausted, the flame goes out as quietly as the flame of a candle does, when the tallow is spent.

"Such are the nature and properties of this curious and beautiful substance, when examined in a small way in the laboratory of the chemist. But it frequently happens, that theories perfectly just and elegant in themselves, and confirmed by experiments on a small scale, with a nice apparatus and skilful management, are yet, when attempted in the large and wholesale way, utterly incapable of being reduced to practice; and thus, many a promising plan has ended with performing nothing. But, in the case before us, there are facts, of the description we want to be collected from different quarters, and furnished by individuals unconnected with each other, which fully verify the anticipations of theory, and the conclusions of more limited experiment.

" This substance *(coke)* is the residuum that is found after all the evaporable matter has been expelled from the coal by heat. It comes out from the distilling process in large spungy masses, greatly diminished in weight, but increased in bulk nearly one-third. Though somewhat more difficult of ignition than coal, it burns longer, and gives out a steadier and more intense heat. That it should do so, will not appear strange to our chemical readers, (and who is there now, that does not know something of chemistry?) when it is considered that the quantity of matter, which, in the combustion of coal, is changed from a solid to a state of elastic fluidity, must necessarily carry off much caloric in a latent state; while the glow of the coke radiates with an intensity unimpaired by any demand of this kind. The same respectable chemist we formerly mentioned, bears testimony to the superiority of coke. 'I have learned,' says Mr. Accum*, '*that the heat produced by coke, when compared with that which can be obtained from coal, is at least as 3 to 2.*' Thus he found, that it required three *bushels* of coal to distil a given quantity of water, and only two of coke. He tried the two substances also by combustion, with a certain measure of oxygen gas, by the fusion and the reduction of metals, &c.; and the same result was obtained,—a result certainly not unimportant, since it proves that, by being forced to yield the material of a beautiful light, coal is actually improved very considerably in its power of giving heat.

" Before taking leave of Mr. Winsor, we shall present the reader with the results of his analysis of coal, which, we should have been cautious of admitting among authentic facts, had not the Committee declared, that the experiments were repeated in their presence, and that they corroborated Winsor's printed statement in the most satisfactory manner. *Two pecks of Newcastle coal, weighing 36 lb., produced three pecks of coke, weighing* 24 *lb.* 2 *oz., about* 3½ *lb. of oily tar, and about* 4½ *of alkaline liquor; and, as the only other product was gas, it is concluded that gas constituted the remainder of the weight, amounting nearly to four pounds.*"

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* Appendix to Report of the Committee, &c.

59. I shall collect here the effect of several kinds of fuel in producing heat, as given by authorities which have come under my observation, and afterwards make a comparative abstract of the result. The distillation of water is a simple and satisfactory mode of comparing the effects of fuel.

60. Mr. Dalton says, for the sake of those who are more immediately interested in the economy of fuel, that the heat given out by the combustion of 1 *lb. of charcoal*, and, perhaps, also of pit-coal, is sufficient (if there were no loss) to raise 45 *or* 50 *lbs. of water* from the freezing to the boiling temperature; or it is sufficient to convert

7 or 8 lbs. of water into steam. If more than this weight of coal be used, there is a proportionate quantity of heat lost, which ought, if possible, to be avoided [*].

61. In Dr. Black's Lectures, vol. i. page 184, we have the following note: " 100 *pounds weight of the best Newcastle coal, when applied by the most judiciously constructed furnace, will convert about* $1\frac{1}{2}$ *wine hogshead* [†] *of water into steam that supports the pressure of the atmosphere.*

62. By this account, observes Count Rumford, which he (Mr. Kirwan) tells me is founded on experiments made by Mr. *Lavoisier*, it appears, that equal quantities of water under equal surfaces, may be evaporated, and consequently equal heats produced——

By 403 lbs. of coaks,	or in measure	By 17 of coaks,
600 — of pit-coal,		10 of pit-coal,
600 — of charcoal,		40 of charcoal,
1089 — of oak,		33 of oak [‡].

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[*] Dalton's Chemical Philosophy, page 82.

[†] Equal to 12.63 cubic feet.

[‡] Rumford's Essays, vol. ii. page 134.

"From the result of my 20th experiment, it appeared that $20\frac{1}{10}$ *lbs. of ice-cold water might be heated* 180 *degrees, or made to boil under the mean pressure of the atmosphere, at the level of the surface of the ocean, with the heat generated in the combustion of* 1 *lb. of pine-wood.* Computing from the result of this experiment, and from the relative quantities of heat producible from pine-wood and from pit-coal, it appears that *the heat generated in the combustion of* 1 *lb. of pit-coal, would make* $36\frac{3}{10}$ *lbs. of ice-cold water boil.*—Hence it appears, that pit-coal should heat 36 times its weight of water, from the freezing point to that of boiling; and as it has been found by experiments, made with great care by Mr. Watt, that nearly $5\frac{1}{4}$ times as much heat as is sufficient to heat any given quantity of ice-cold water to the boiling point, is required to reduce that same quantity of water, *already boiling hot*, to steam; according to this estimation, *the heat generated in the combustion of* 1 *lb. of coal, should be sufficient to reduce very nearly* 7 *lbs. of boiling hot water to steam* *."

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* Count Rumford's Essays, vol. ii. page 136, 137.

Dr. Crawford found, by an experiment contrived with much ingenuity, and which appears to have been executed with the utmost care, that the heat generated in the combustion of 30 grains of charcoal raised the temperature of 31 lbs. 7 oz. Troy= 181.920 grains of water 1$\frac{71}{100}$ degrees of Fahrenheit's thermometer, *when none of the heat generated was suffered to escape.* Consequently, *the heat generated in the combustion of* 1 *lb. of charcoal, would be sufficient to heat* 57.608 *lbs. of ice-cold water* 180 *degrees, or to make it boil;* for 3157.9 grains of charcoal are to 181.920 grains of water, as 1 of charcoal to 57.608 lbs. of water.

From the result of Mr. Lavoisier's experiments, it appeared that the quantities of heat generated in the combustion of equal weights of charcoal and dry oak, are as 1089 to 600. Hence we may conclude, *that equal quantities of heat are generated by* 1 *lb. of charcoal and* 1.815 *lbs. of oak;* consequently, that the heat generated in the combustion of 1.815 lbs. of oak, would heat 57.608 lbs. of ice-cold water,—or 1 lb. of oak, 31.74 lbs. of ice-cold water 180 degrees, or cause it to boil; *were no part of the heat generated in the combustion of fuel lost* *.

63. " The comparative examination of the intensity of *the heat produced by burning charcoal and charred turf*, proves that *the heat of the latter is* (to that of the former) *nearly in the proportion of three to one* †.

64. " Mr. Watt finds, that it requires eight feet surface of boiler to be exposed to fire, to boil off one cubic foot of water per hour, and that *a bushel or* 84 *lbs. Newcastle coal*, so applied, *will boil off from eight to twelve cubic feet* ‡.

65. " The heat expended in boiling off *a cubic foot* of water, is *about six times* as much as would bring it to a boiling heat

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* Count Rumford's Essay, vol. ii. page 139, 140.

† " Inquiry into the comparative intensity of heat produced by the combustion of charcoal and charred turf," in the Memoirs of the Academy of Sciences of Paris. Repertory of Arts, vol. v. p. 419.

‡ En. Brit. Supplement.

from the medium temperature, (55°) in this climate*."

66. Mr. Watt, I believe, for his steam-engines, in situations where wood is the fuel employed, allows *three times the weight of wood, that he does of Newcastle coal.*

67. Newcastle coal produces much more heat than the generality of Scotch coal. *A bushel of Newcastle coal, which weighs ¾ of a cwt. is reckoned to produce as much heat as a cwt. of Glasgow coal.*

68. Small coal or culm, is much used for steam-engines. From repeated trials, made in the neighbourhood of Glasgow, *it requires just double the weight of culm that it does of coal to produce the same heat.* At the prices in 1808, the cost of culm was to that of coal, supplying the same work as 12 is to 14, thus producing a saving of ⅐ by the use of culm.

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* En. Brit. Supplement.

69. "A wax candle ¾ of an inch in diameter, loses a grain of its weight in 37 seconds, and consumes about three grains, or 9 cubic inches of oxygen gas, producing heat enough to raise the temperature of about 15000 grains of water a single degree. According to the experiments of Mr. Lavoisier and Mr. Laplace, the combustion of 10 grains of phosphorus, requires the consumption of 15 grains of oxygen; the combustion of 10 grains of charcoal 26, and of hydrogen gas 56; and, by the heat produced during the combustion of a pound of phosphorus, 100 pounds of ice may be melted; during that of *a pound of charcoal*, 96½; of hydrogen gas, 295½; of wax, 133; and of olive oil, 149; and during the deflagration of a pound of nitre, with about one-sixth part of its weight of charcoal, 12 pounds of ice may be melted *."

70. The following table contains a comparative abstract of the effect of several kinds of fuel in producing heat.

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* Young's Nat. Phil. vol. i. p. 634.

The numbers in the fourth column, point out the Articles in this Essay which contain the authority upon which the abstract is made, or on which the proportions are calculated.

1.	2.	3.	4.	
	Sufficient to raise from the freezing to the boiling point, lbs. of water.	Sufficient to convert into steam, lbs. of water,	Articles of this Essay referred to.	
1 lb. charcoal or pit coal at a maximum,	54 to 50	7 or 6	60	Dalton.
1 lb. of pit-coal,	$36\frac{3}{10}$	7.	62	Count Rumford.
1 lb. charcoal,	57.608	10.9	62	Crawford.
1 lb. dry oak,	31.7		62	Lavoisier.
1 lb. of pine-wood,	20.1		62	Count Rumford.
1 lb. of Newcastle coal,		6.	64	Watt.
1 lb. do. do.		7.89	61	Black.
1 lb. do. do.		6.25	63	Watt.

SECTION V.

Of the Motion of Heat.

71. The temperature of bodies being liable to perpetual fluctuation, to determine the nature of the motion of heat in the same body, and in its passage from one body to another, arising from its incessant tendency to an equilibrium, becomes of much practical importance. Dr. Ingenhouse to show the relative conducting power of the different metals, made this simple experiment;—he took equal straight pieces of stout wire of the different metals, drawn through the same hole and of the same lengths, and dipping them into melted wax. He then held one end of each of these wires in boiling water, and observed how far the coating of wax was melted by the heat communicated through the metal, and with what celerity the heat passed.

72. The property by which bodies receive, and part with heat when in com-

munication with others of a different temperature, is termed their *conducting power.* Those which have their temperature quickly altered by communication with other bodies, are said to be better conductors of heat, than those which receive and part with it more slowly.

73. The power of conducting heat, varies greatly according to the nature of the subject. In general, it may be remarked that dense bodies are the best conductors of heat, and that those which are more rare conduct it very imperfectly. The metals, for instance, are good conductors. Earthy substances conduct more slowly. Wood is a very imperfect conductor. Hair, fur, feathers, &c. which form the covering of animals, are still inferior in their conducting power. The same matter in its different states of aggregation, differs in this property. Thus an iron bar or an iron plate is a much better conductor than iron filings, and wood than sawdust.

74. But though these experiments were very ingenious and simple, and, perhaps, sufficiently accurate for a great variety of practical purposes, yet philosophers, when the truth can be more nearly ascertained, are not satisfied with these approximations. Professor Leslie described to me an apparatus, which seems well calculated for this purpose, but which he had not then applied. I hope, however, he will soon favour the public with the result of his inquiries on this subject.

Dr. Ingenhouse, from his experiments, concluded, "that the conducting powers of the metals which he examined, were in the following order *.

Silver,	
Gold,	
Copper,	nearly equal.
Tin,	
Platinum,	much inferior to the others.
Iron,	
Steel,	
Lead,	

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[*] Jour. de Phys. 1789, p. 68.

"Next to metals, stones seem to be the best conductors; but this property varies considerably in different stones. Bricks are much worse conductors than most stones.

"Glass seems not to differ much from stones in its conducting power. Like them, it is a bad conductor. This is the reason that it is so apt to crack on being suddenly heated or cooled. One part of it, receiving or parting with its caloric before the rest, expands or contracts, and destroys the cohesion.

"Next to these come dried woods. Mr. Meyer* has made a set of experiments on the conducting power of a considerable number of woods. The result may be seen in the following TABLE, in which the conducting power of water is supposed = 1.

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* Ann. de. Chim. xxx. 32.

BODIES.	*Conducting Power.*
Water	=1.00
Diaspyrus ebenum, or ebony	=2.17
Pyrus malus, or the common apple-tree	=2.74
Fraxinus excelsior, or the ash-tree	=3.08
Fagus sylvatica, or the beech tree	=3.21
Carpinus betulus, or common hornbeam	=3.23
Prunus domestica, or common plum tree	=3.25
Ulmus, or the elm	=3.25
Quercus robur pendunculata, or common oak	=3.26
Pyrus communis, or the common pear tree	=3.32
Betula alba, or the common birch tree	=3.41
Quercus robur sessilis, the low growing oak	=3.63
Pinus picea, or yew leaved fir	=3.75
Betula alnus, or the alder tree	=3.84
Pinus sylvestris, or the wood pine	=3.86
Pinus abies, or the European spruce fir	=3.89
Tilea Europæa, or the European lime tree	=3.90

"Charcoal is also a bad conductor: According to the experiments of Morveau, its conducting power is to that of fine sand : : 2 : 3*. Feathers, silk, wool, and hair, are still worse conductors than any of the substances yet mentioned. This is the reason that they answer well for articles of clothing. They do not allow the heat of the body to be carried off by the cold external air. Count Rumford has made a very ingenious set of experiments on the conducting power of these substances *. He ascertained that their conducting power is inversely as the fineness of their texture.

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* Ann. de Chim. xxvi. 225.

" The conducting power of liquid bodies has not been examined with any degree of precision. I find, by experiment, that the relative conducting powers of mercury, water, and lintseed oil, are as follows:

I. *Equal Bulks.*

Water - - - - - - - =1
Mercury - - - - - =2
Lintseed oil - - - - =1.111

II. *Equal Weights.*

Water - - - - - - - =1
Mercury - - - - - =4.8
Lintseed oil - - - - =1.085

" As bodies conduct caloric in consequence of their affinity for it, the inequality of their conducting power is a demonstra-

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[*] Phil. Trans. 1792.

tion that their affinities for caloric are also unequal. It is probable that their affinity for caloric is in all cases the inverse of their conducting power. If, therefore, we were in possession of the relative conducting powers of bodies, the inverse of that would give us the affinities in absolute numbers. Thus the affinity of

Water is - - -	$=1$ - - -	$=1$
Mercury - - -	$=\frac{1}{4.8}$ - -	$=0.208$
Lintseed oil - -	$=\frac{1}{1.085}$ - -	$=0.921$ *

75. "When a fluid is heated at its surface, the heat gradually and slowly descends in the same manner as along a solid; and fluids seem to have a difference in their conducting power, analogous to that of solids. But when the heat is applied to the bottom of a vessel containing a fluid, the case is very different, the heated particles of the fluid, in consequence of their diminished specific gravity, form an ascending current, and rise to the surface, communicating a

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* Thomson's Chem. vol. i. p. 327—330.

portion of heat in their ascent to the contiguous particles, but still retaining a superiority of temperature; so that the increase of temperature in the mass is first observed at the surface, and is constantly greatest there till commencement of ebullition in liquids, at which period the temperature is uniform. The conducting power of fluids then arises from two distinct sources: the one is the same as solids, namely, a gradual progress of the heat from particle to particle, exclusive of any motion of the particles themselves; the other arises from the internal motion of the particles of the fluid, by which the extremes of hot and cold are perpetually brought into contact, and the heat is thus diffused with great celerity. The latter source is so much more effectual than the former, that some have been led, though without sufficient reason, to doubt the existence of the former, or that fluids do convey heat in the same manner as solids.

"Nothing appears then, but that the communication of heat from particle to particle, is performed in the same way in fluids as in solids; the rapidity of its diffusion in fluids, is to be ascribed to a hydrostatical law. But there is another method by which heat is propagated through a vacuum, and through elastic fluids, which demands our particular notice. By this we receive the heat of the sun, and by this, when in a room, we receive the heat of an ordinary fire. It is called the *radiation* of heat; and the heat so propelled, is called *radiant heat* *."

76. "The activity of these rays, says Count Rumford, may be shown in different ways, but in no way, in a more striking manner, than by the following simple experiment. When the fire burns bright upon the hearth, let the arm be extended in a straight line towards the centre of the fire, with the hand open, and all the fingers extended and pointing to the fire.

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* Dalton, p. 100, 101, 102.

If the hand is not nearer the fire than the distance of two or three yards, except the fire be very large indeed, the heat will scarcely be perceptible; but if without moving the arm, the wrist be bent upwards, so as to present the inside, or flat of the hand perpendicular to the fire, the heat will not only be very sensibly felt, but if the fire be large, and if it burns clear and bright, it will be found to be so intense as to be quite insupportable *."

77. "Till lately, we have been used to consider the light and heat of the sun, as the same thing. But Dr. Herschel has shown, that there are rays of heat proceeding from the sun, which are separable by a prism, from the rays of light; they are subject to reflection like light and to refraction, but in a less degree, which is the cause of their separability from light. The velocity of radiant heat is not known, but it may be presumed to be the same as that of light, till something appears

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* Rumford's Essays, vol. ii. p. 47.

to the contrary. An ordinary fire of red hot charcoal, or, indeed, any heated body, radiates heat, which is capable of being reflected to a focus, like the light and heat of the sun; but it should seem not to be of sufficient energy to penetrate glass, or other transparent bodies, so as to be refracted to an efficient focus *.

78. "Dr. Hoffmann, appears to have been the first that collected the invisible heat of a stove into a focus, by the reflection of one or more concave mirrors. Buffon, Saussure, Pictet, and Mr. King, made afterwards similar experiments on the heat of a plate of iron, and of a vessel of boiling water †."

79. Professor Lesslie, has lately ascertained and published in his "Inquiry on Heat," several new and important facts, relative to the radiation ‡ of heat. Some

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* Dalton, p. 101 and 102.

† Young's Nat. Phil. p. 637.

‡ Professor Lesslie calls this the pulsation of heat. The term radiation, not being applicable according to his theory.

of the principal of these facts, it will be proper here to mention; but I shall first endeavour to give some idea of the instruments which he used.

These were concave mirrors of tin-plate, about 14 inches in diameter, and tin-plate cannisters of different sizes, one side of which was kept clean and bright, the opposite was covered with writing paper, or painted with lamp black; the other sides were left for miscellaneous service. With these was employed an ingeniously constructed and delicate air thermometer, than which nothing could be more simple and commodious, and for the invention of which, the philosophical world are indebted to Mr. Lesslie. It is thus constructed.

80. "Two glass tubes of unequal lengths, each terminating in a hollow ball, and having their bores somewhat widened at the other ends, a small portion of sulphuric acid tinged with carmine being introduced into the ball of the longer tube, are joined together by the means

of a blow-pipe, and afterwards bent into nearly the shape of the letter U, the one flexure being made just below the joining, where the small cavity facilitates the adjustment of the instrument, which, by a little dexterity, is performed by forcing with the heat of the hand a few minute globules of air from the one ball into the other. The balls are blown as equal as the eye can judge, and from four-tenths to seven-tenths of an inch in diameter. The tubes are such as are drawn for mercurial thermometers, only with wider bores; that of the short one, and to which the scale is affixed, must have an exact calibre of a fiftieth or a sixtieth of an inch; the bore of the long tube need not be so regular, but should be visibly larger, as the coloured liquor will then move quicker under any impression. Each leg of the instrument is from three to six inches in height, and the balls are from two to four inches apart. The lower portion of the syphon is cemented at its middle to a slender wooden pillar inserted into a round or square bottom, and such that the balls stand on a level with the centre of the speculum. A moment's attention to the construction of this instrument will satisfy us that it is affected only by the *difference* of heat in the corresponding balls, and is calculated to measure such difference with peculiar nicety. As long as both balls are of the same temperature, whatever this may be, the air contained in the one will have the same elasticity as that in the other, and consequently the intercluded coloured liquor, being thus pressed equally in opposite directions, must remain stationary. But if, for instance, the ball which holds a portion of the liquor be warmer than the other, the superior elasticity of the confined air will drive it forwards, and make it rise in the opposite branch above the zero, to an elevation proportional to the excess of elasticity or of heat. The interval between freezing and boiling water being distinguished into an hundred equal parts, called *centigrade*, each of these subdivided decimally, constitute the degrees which I employ, and which, following up the same system of nomenclature, would be termed *milligrade*". *See Fig.* 6, *Plate* 1.

81. "I may notice a simple improvement, or modification of the differential thermometer, which fits it for estimating with nice precision, the intensity of the diffuse radiations of heat. It has still the form represented by *Fig.* 2,* only the ball of the graduated stem is completely gilt or enamelled with gold. But the two balls exposed to the same influence, will now receive very different impressions, and the excess of energy, which the instrument marks, must, therefore, amount nearly to seven-eighths of the whole vibratory tide. Hence, it will measure the quantities of heat that are continually thrown from the fire into a room. We can thus calculate, with equal ease and certainty, the ralative advantages arising from various constructions of chimnies †."

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* Mr. Leslie's *Fig.* 2, is the same as *Fig.* 6, *Plate* 1, of this Essay.

† Leslie on Heat, p. 9—11, 561.

82. Mr. Leslie has also applied this instrument, in a very simple and ingenious manner, by covering one of the balls with thin silk, and moistening it to act as a hygrometer, or instrument for measuring the degree of moisture in the atmosphere. An instrument of the kind has long been wanted in the cotton and other manufactures. Respecting Mr. Dalton's hygrometer, as also those of Berezelius, and Mr. Gough, the reader will find information in the Philosophical Magazine, vol. xxxiii. p. 39, 177.

83. The following are some of the principal facts, which were discovered or confirmed by Professor Leslie.

1st, If a given vessel be filled with hot water, the quantity of heat which radiates from it, depends chiefly upon the nature of the exterior surface of the vessel. Thus, if a canister of tinned iron be the vessel, then a certain quantity of heat radiates from it; if the said vessel be covered with black paint, paper, glass, &c.

it will then radiate 8 times as much heat in like circumstances *.

84. 2d, " If the bulb of the thermometer be covered with tin-foil, the impression of the radiant heat is only $\frac{1}{5}$ of that upon the glass surface.

85. 3d, " A metalic mirror reflects 10 times as much heat from an ordinary fire, or from any heated body, as a similar glass mirror does. This last is found to reflect the heat from its *anterior* surface, and not from the quick-silvered one, which is the most essential in reflecting solar light, and heat. Here then is a striking difference between solar and culinary heat.

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* When one side of a tin-plate canister was coated with lamp black, another with writing paper, a third with glass, and the fourth left bare, or covered with tin-foil, the differential thermometer rose when the

Black side was exposed to the speculum to	100
Writing paper	98
Glass	90
Tin-plate, or tin-foil	12

"From these facts it appears, that metals and other bodies which are eminently disposed to *reflect* radiant heat, are not disposed to *absorb* it in any remarkable degree; whereas black paint, paper, glass, &c. are disposed to *absorb* it, and consequently to *radiate* it again in proper circumstances."

86. 4th, "The heat radiating from hot water, does not seem capable of being transmitted through glass like the solar heat.

87. 5th, "When a heated body is whirled through the air, the additional cooling effect is directly proportional to the velocity *."

88. Mr. Dalton infers from his experiments, contrary to the results obtained by Mr. Leslie, that the same law of progressive cooling (viz. that "*the temperature descends in geometrical progression to equal*

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* Dalton's Chem. Phil. pages, 103, 104, 105.

*increments of time**") applies to a metalic as well as to a vitreous surface †. The surface, however, materially affects the whole time which is occupied in cooling.

89. "After a long and intricate, but ingenious investigation, Mr. Leslie finds the cooling power of the air upon a hollow sphere, six inches in diameter, and filled with boiling water, to be as follows: namely, in each minute of time, the fluid loses the following fractional parts of its excess of temperature, by the *three distinct sources of refrigeration* in the air undermentioned.

"By *abduction*, that is, the proper conducting power of air, the 524th.

"By *recession*, that is, the perpendicular current of air excited by the heated body, the h×21715th.

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* Dalton, p. 111.

† "The term *surface* is used throughout this discourse, in its physical and not its mathematical acceptation. I employ it to signify a stratum of matter of a certain finite depth, yet of such extreme tenuity as almost to escape the cognizance of the senses. Leslie on Heat, p. 85."

" By *pulsation*, or *radiation*, the 2533d part from a metalic surface, and eight times as much, or the 317th part from a surface of paper. It should be observed, that Mr. Leslie contends that air is instrumental in the radiation of heat, which is contrary to the received opinion *."

In the above fractions, Mr. Dalton does not acquiesce, and after detailing his own experiments, he proceeds as follows:

" It will be proper now to inquire into the cause of the difference in the times of cooling, arising from the variation of surface. Mr. Leslie has shown the surface has no influence upon the time of cooling, when immersed in water; it should seem then, that the difference of surfaces in the expenditure of heat, arises from their different powers of radiation solely; indeed, Leslie has proved by direct experiments, that the heat radiating from a vitreous or paper surface, is 8 times as great, as that from a metallic surface. Taking this for granted, we can easily find the portions of heat dispersed by radiation, and conducted away by the atmosphere. For let 1 denote the quantity of heat conducted away by the atmosphere, from a vitreous or metallic surface, in any given small portion of time, and x the quantity radiated from a metallic surface in the same time; then $8\ x$ will be the quantity radiated from a vitreous surface in that time; and from the result of the last experiment we shall have $2 : 3 :: 1+x : 1+8\ x$; whence $2+16\ x = 3+3\ x$, and $x=\frac{1}{13}$; this gives $1\frac{1}{13}$ for the whole heat discharged by metal, and $1\frac{8}{13}$ for that discharged by glass in the same time, where the unit expresses the part conducted, and the fraction the part radiated. That is, from a metallic surface, 13 parts of heat are conducted away by the air, and 1 part radiated; from a vitreous surface, 13 parts are conducted, and 8 parts radiated, in a given time.

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* Dalton, page 106.

"The quantity of heat discharged by radiation, from the most favourable surface, therefore, is probably not more than 4 of the whole, and that conducted away by the air not less than .6—Mr. Leslie, however, deduces .57 for the former, and .43 for the latter, because he found the disproportion in the times of cooling of vitreous and metallic surfaces, greater than I find it in the lower part of the scale."

"The obvious consequences of this doctrine, in a practical sense, are:"

"1st, In every case where heat is required to be retained as long as possible, the containing vessel should be of metal, with a bright clear surface."

"2d, Whenever heat is required to be given out by a body with as much celerity as possible, the containing vessel if of metal, ought to be painted, covered with paper, charcoal, or some animal or vegitable matter; in which case the heat given out, will be 3 parts for 2 from a metallic surface *." For it is to be recollected, that the nature of the *surface* affects only that part of the heat which is *radiated.* The other two causes of refrigeration, called, by Mr. Leslie, *abduction* and *recession*, or which come together under the more usual name of *combined heat*, remain the same whatever be the nature of the surface.

90. Mr. Leslie, in an early part of his inquiry, having, as we saw (Art. 83.) ascertained that bodies differ widely in their power of projecting, absorbing, and reflecting heat, instituted a set of experiments, with a view to ascertain the limits of this variation. From these experiments, he found that the *chemical qualities* of the heating surface, have a considerable influence, as will appear from the following summary of the results of his experiments.

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* Dalton's Chem. Phil. 115, 116, 117.

The standard effect of a coat of lamp-black being	100
The effect of bright surface of tin	12
Iron or steel is as	15
Mercury above	20

All oxydes act more powerfully as they recede from a metallic state.

Clean lead, but rough, being as	19
Lead tarnished by exposure to the air	45
Black lead or plumbago	75
Red lead, or minium as	80
Dry size, or isinglass	80
Sealing wax and rosin are nearly equal to paper, which is	98
Ice	85

The *polish*, where not naturally great, diminishes its action. Thus, tin-plate when hammered, (which Mr. Leslie calls planished tin,) its power to propagate heat is only half that of ordinary tin-plate. The roughening of glass, however, does not increase its power of projecting heat.

That of tin is doubled by covering it with *striæ* or furrows made in one direction, by a file or toothed-plane. This remarkable effect cannot be owing to the greater surface exposed, because the increase of surface is exactly counteracted by the increase of obliquity, according to a law which Mr. Leslie established by experiment; and, besides, it is found that cross furrows by striating the surface in the other direction, nearly destroys the effect of those first made *.

The *thickness* of the radiating surface has a great influence on its powers of action, a thin film of isinglass produces a radiation as 26, a thick film as 42, when the thickness exceeds the thousandth part of an inch, any subsequent increase does not augment its action.

Mr. Leslie is of opinion, that these differences in projective power, may be resolved into the variations of the bodies, as to hardness and softness, and shows that the addition of moisture and still more of a mucilaginous substance, considerably augments the action of a surface painted black.

* Leslie on Heat, p. 78, 85.

Mr. Leslie doubts whether the quality of *colour* exerts any influence at all, in modifying the projective and absorbent powers of bodies.

The various reflecting powers of different surfaces, bears some inverse ratio to their absorbent and projective powers, although many circumstances occur to prevent this ratio from being expressed by one universal law.

91. Mr. Leslie having investigated the various circumstances which affect the progress of the cooling of bodies, when the enclosing boundary is considered a mere *physical surface*, (Art. 88.) but where the surface of a body is defended by a covering of slow conducting materials, the process of refrigeration, is retarded in proportion to the thickness of the exterior coat. On this principle depends the utility of cloathing, whether natural or artificial, also that of covering steam tubes with slow conducting materials to prevent the dissipation of heat. But it requires a

considerable thickness of such materials, to counteract the effect of the *physical surface* in propagating heat. Thus, Mr. Leslie informs me, that he found it required three plies of flannel to overcome its radiating power.

92. " A fluid of such extreme rarity as air, if confined round a heated body, must like those spongy substances, have a decided influence to retard the operation of cooling. And this property is most distinctly perceived, though on a very limited scale. If a series of hollow cylindrical vessels be constructed of very thin brass, to fit into one another like a nest of boxes, the first or smallest, filled with boiling water, and with a fine thermometer inserted, being enclosed in each of the rest consecutively, according to the order of their width, and kept equally separate from the sides and bottom, by resting against protuberant points or a slender chequered ring; on plunging the canister with its adapted case, in a tub of water, the rate of cooling will be found

at every successive trial, regularly to *diminish* till the space of intercluded air comes to *exceed a quarter of an inch*, when the effect will be reduced to about a sixteenth part. Beyond this limit scarcely any farther decrease is observed, there now being room sufficient to allow that active fluid to develope its mobility, which fully compensates for the increasing distance of communication. A limit so narrow, must evidently preclude the great majority of instances that would occur. The property of confined air to retard the progress of cooling, is, therefore, founded on a principle not quite obvious, and not hitherto explained. By employing a series of concentric cases, or *septa*, this effect is wonderfully heightened. Yet a subject in itself so curious, and of such vast importance in the economy of heat, has been generally overlooked, or only treated in a vague and superficial manner. As I purpose to consider it with some attention, I shall, for the sake of clearness, divide it into three branches: 1st, when the surface of the internal canister, and its several cases are metallic; 2d, when those surfaces are all painted, or consist of glass; and 3d, when they are composed partially of both sorts.

93. " 1st, When all the surfaces by which the included or exterior air is bounded, are metallic.

" Suppose the canister so large that its surface may be regarded as equal to that of the exterior case, which is separated from it, only by a narrow space. After an equilibrium is attained, the case will receive and discharge heat exactly in the same proportion; it must, therefore, be just as much hotter than the external, as it is colder than the included air. But this confined portion, will have evidently the mean temperature of its bounding sides. Consequently, reckoning the heat of the room as a standard, the temperature of the outer case, must be equal to half the difference between itself and the temperature of the canister, or equal to one-third of this whole quantity. Hence, the canister under the shelter of its case, will cool three times slower than if it were exposed naked. Thus, when the central heat is 30°, that of the exterior surface will be 10°, and their arithmetical mean, or 20°, will be the temperature of the confined stratum of air. Therefore, the rate of internal communication which cools the one surface in the same degree as it heats the other, will be as 10°, or equal to the discharge into the free surrounding atmosphere.

"Imagine a second case to be now added. The mean temperature of the air which that contains, is equal to its difference from the mean temperature of the air included within the first case; and either of these measures is equal to half the excess of the central heat above this last mean. Hence, the outmost case will have only one-fifth part of the temperature of the canister; and, consequently, by the intervention of a double case, its rate of cooling is diminished five times. For the sake of illustration, let the temperature of the central mass be 25°, then that of the first case will be 15°, and that of the second case 5°, the mean temperature of the inner stratum of air will be 20°, and that of the outer one 10°, the surface of the canister will regularly discharge a portion of heat as 5°, the next *septum* will receive and deliver the same to the contiguous air; and the external case will absorb this portion, and finally discharge it into the air of the apartment.

"Pursuing the same mode of reasoning, it would be easy to show, that, with three concentric cases, the canister would cool seven times more slowly; and with four such cases, nine times more slowly. In general, the degree of diminution is equal to double the number of cases increased by one, or the number of surfaces concerned: it is hence represented by the progression of the odd numbers, 3, 5, 7, 9, 11, 13, &c.

"This result will appear sufficiently accurate when the canister is of considerable size, and the cases not too widely disjoined; for instance, if the canister exceeds a foot in diameter, and the intervals between the cases are each of them not more than half an inch *.

EXPERIMENT.

"A cylindrical canister of planished tin, two inches in diameter and equal height, filled with boiling water, took 117′ to cool, from 30° to 10°; but enclosed within a similar canister of four inches in diameter, it required 176′ to make the same descent. Another cylindrical canister of four inches, and which took 156′ to cool from 20° to 10°, required 356′, when cased with a similar one of five inches; yet, the interval being filled with flour, the effect was performed in 324′. And a square canister of three inches, that cools from 20° to 10° in 117′, took 335′ to perform the same effect, after it was enclosed within two similar cases of four and five inches *.

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* Leslie on Heat, pages 373—378.

94. " 2d, The next division of the problem is, where the canister and its surrounding cases are painted or vitreous. This condition will be found to alter materially the proportion of the result. When two such surfaces with unequal degrees of heat, are made to front each other, they will not, like metallic plates, act the same as if they were quite insulated; but must, by their pulsatory energies, exert a mutual influence to accelerate the progress towards an equilibrium. If their visual magnitude be very considerable, or their extent great in comparison of their distance, almost the whole of those opposite dispersive pulsations, will be intercepted and received on both sides. But, with a moderate difference of temperature, the vibratory discharge, constitutes very nearly the half of the ordinary measure of communication. Therefore,

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* Pages 380, 381.

the vitreous or painted surfaces must emit or absorb heat, one-half faster than if they were removed beyond each others sphere of action, but accompanied by the same intercluded atmosphere.

"If the one surface be completely encompassed by the other, it is evident, that the exterior will receive all the diverging pulsations; and, if the interior be not disproportionately small, it must, in its turn, intercept those which are reciprocally convergent*.

95. "3d, The last branch into which the problem divides itself, is, that where vitreous and metallic surfaces are promiscuously combined. But as such possible combinations must, evidently, be very numerous, I shall select only their principal varieties.

"Suppose a painted canister is included within a bright tin case. If the reflective power of the internal surface of the case were absolutely complete, the progress of refrigeration would be exactly the same as if the canister had a metallic lustre; for the discharge of heat by pulsation would then be rendered altogether abortive, being constantly sent back from the case to its source, and there re-absorbed. The effect would thus be comparatively much greater than in any of the preceding instances. However, the defective reflection, or partial absorption of the tin, sensibly modifies the result. It is obvious, that the mean temperature of the intercluded air, will be determined in the same manner as before. But, while a polished metallic surface emits nine parts of heat, a painted one disperses sixteen. Of the sixteen parts, therefore, which the canister is capable of discharging, no more than ten prove really effective, the additional part only being absorbed by the inner surface of the case. Hence, the temperature of the exterior surface, must be somewhat greater than the mean internal difference, to enable it to disperse its invigorated accesions of heat into free space.

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* Pages 385, 386.

"Let the position be now reversed, the surface of the canister being clear, and its exterior case painted on both sides. This case will, therefore, absorb at its inner surface, ten parts of heat, of which the canister makes an effective discharge; but, with the same difference of temperature, it would disperse sixteen parts into the free external atmosphere[*].

"It would be superfluous to prosecute this subject any farther. The examples which have been chosen are sufficient to explain the varying mode of investigation. When several cases are employed, alternately vitreous and metallic, the effect is nearly the same as if they were all metallic; but the general influence, will depend chiefly on the quality of the outmost surface. For the same reason, the vitreous or painted surfaces, will have much less power to retard the process of cooling when they lie adjacent, than when they are interspersed *.

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[*] Pages 390, 391, 392.

" With equal facility, may be determined the progress of refrigeration, which obtains on the immersion of the apparatus in a liquid mass. Since the discharge of heat by external pulsation is now precluded, the nature of the extreme boundary, will have no influence whatever on the measure of effect. This result must depend almost entirely on the quality, the position, and the number of the interior surfaces †.

" A cylindrical canister of planished tin, three inches in diameter and height, and which in still air takes 117′ to cool, from 20° to 10° would require 249′ if included regularly within a similar cylinder of four inches, but only 185′ if the whole were immersed in a tub of water. The same canister when painted, would, in a

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* Page 394. † Page 396.

close room, cool in 61′, or, surrounded with its case likewise painted, in 98′, and both plunged in water would take only 64′.

"In all these examples, the canister and its several cases are regularly separated from each other by intervals of half an inch. If the divisions approach nearer, their effect soon becomes altered; for the successive strata of intercluded air as they diminish in thickness, lose in some degree their internal mobility, and begin passively to transmit heat like a solid mass. When the terminating surfaces mutually approximate, not only is the fluidity of the thin shells of air proportionally cramped, but the power of communication is likewise invigorated by the shortness of the passage, and consequently the quicker gradation of temperature. On both these accounts, therefore, the quantity of transmission will increase with most rapid progress, as the *septa* contract their limits. Thus, a cylindrical tin canister of three inches in diameter and height, placed within a similar one of four inches, will cool about one-sixtieth part faster, if shifted from its position in the middle to a quarter of an inch from the bottom; and nearly one-nintieth part still faster, when advanced only an eight of an inch from that boundary. Hence, we may compute that a stratum of air one quarter of an inch thick, transmits through its substance, about a sixth part of the heat which it is fitted to communicate in the ordinary mode, and if reduced to half this thickness, it will deliver nearly equal shares in both ways.

" But to discover more accurately the progress of this internal transmission, I procured another intermediate cylinder of tin, with a moveable lid and three inches and three quarters in diameter. The three inch canister enclosed within this, had its rate of cooling reduced to 7-15ths. But calculation gives $\frac{45}{97}$, the difference being only $\frac{4}{1455}$; and, consequently, the aberration or accelerating influence, corresponding to an interval of three-eights of an inch, must be extremely small. The diameters of the cylinders are as 4 and 5, and their surfaces as 16 and 25. Therefore, the temperature of the internal canister being denoted by unit, that of the outer case is $\frac{7}{15}\times\frac{16}{25}=\frac{112}{375}$. The mutual difference is $\frac{263}{375}$, and hence, the canister exceeds the temperature of the interjacent air, by $\frac{25}{25+16}\times\frac{263}{375}=\frac{160\frac{15}{41}}{375}$. This fraction will express the ordinary measure of communication; but the actual discharge of heat is 7-15ths, or $\frac{175}{375}$, and, therefore, $\frac{14\frac{26}{41}}{375}$ or about the twelfth part of the whole, is conveyed away through the stratum of air by passive transmission.

" When the intermediate cylinder was included within the four inch one, their interval being only the eight part of an inch, the deviation appeared now to have most rapidly increased. The rate of cooling, instead of 17-47ths was only reduced to 17-26ths. The opposite surfaces being as 225 to 256, or very nearly as 15 to 17, the temperature of the exterior one is $\frac{17}{26}\times$

$\frac{15}{17}=\frac{15}{26}$, and, consequently, the internal canister must exceed the temperature of the thin stratum of intercluded air by $\frac{11}{26}\times\frac{17}{32}=\frac{187}{832}$. This must denote the ordinary discharge of heat, but the real consumption is $\frac{17}{26}=\frac{544}{832}$, which is nearly triple the former. Therefore, when the shell of air is only the eight of an inch in thickness, of 31 parts of heat, 10 are carried off by the general process, and 21 by quiescent communication.

"But the close proximity, and still more the partial contact of the canister with its exterior case, has not merely a negative influence to diminish the retardation of cooling. It must actually accelerate the dispersion of heat, since, in effect, it occasions an artificial enlargement of surface. A tin canister of two inches square, will cool one-half slower, when planted in the centre of a similar one of four inches. But if it be made to touch three sides of the case, it will cool about three times faster than at first; for these sides having the same temperature as the canister, and presenting twice its extent of surface, must double the refrigerating action, exclusive of the co-operation of the remaining sides, which will add at least one-half more.

" To produce their proper effect, therefore, it is requisite that the cases should be perfectly detached or insulated. The retardation of the process of cooling, depends entirely on the coldness of the external surface. But metals conduct heat so freely, that even a partial contact might be sufficient to cause an almost equal diffusion. If a round tin vessel of a broad and rather flat shape, have a cap fitted at each end, capable of being drawn out to different small distances, the rate of cooling will continue very nearly the same, through all the gradations from the position of absolute contiguity, till the circular plates are separated by an interval of perhaps three quarters of an inch. The narrow rims embracing the canister, rapidly abstract heat, and convey it to the prolonged boundaries. We, hence, see the defect of the ordinary form of pots with double lids, designed for culinary purposes *."

96. Many useful practical applications of the principles here investigated might be made, Mr. Leslie has proposed a method of preserving ice, by enclosing it within a number of tin canisters, and has applied it for preserving liquids in a cool state in warm climates; on the same prin-

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[*] A late ingenious experimenter, who by the perspicuity and useful tendency of his writings, is deservedly a favourite of the public, has advanced the paradoxical conclusion, that "fluids are non-conductors of heat." And this strange assertion from the celebrity of its author, has been treated certainly with more attention and respect than it otherwise merited (Art. 75.) If nothing more is meant, than that fluids as the consequence of their extreme mobility, convey the impressions of heat chiefly by means of their internal motions, the fact will not be disputed, but though perhaps more distinctly announced, it can have very little claim to originality. If the proposition, however, be taken in its strict sense, it is most palpably erroneous. Were fluids absolutely incapable of conducting heat, how could they ever become heated? Must we suppose that the particles of a fluid can imbibe heat from those of a solid, and yet not receive it from each other? On mixing cold with hot water, a sort of heterogeneous compound will be formed, each molecule retaining without participation, its initial and peculiar temperature. And where no such intermixture can take place, how could water, for instance, be heated by the contact of warm air? But the question really deserves no serious discussion." Leslie on Heat, pages 397—402, 552, 553.

ciple, a good mode of protecting water-pipes from freezing, would be to enclose them in tin-plate tubes, leaving a space of about an inch all round the leaden pipes. It is also well worthy of consideration, how far these principles might be applied in the construction of the casing, for the preservation of the heat of cylinders of steam engines. Its advantages in many situations of steam tubes is quite obvious.

" *Refrigeration of Bodies in various kinds of Elastic Fluids.*

97. "Bodies cool in very different times in some of the elastic fluids. Mr. Leslie was the first, I believe, who noticed this fact; and he has given us the results of his experiments on common air and hydrogeneous gas, of the common density, and also rarefied in various degrees. I made some experiments with a view to determine the relative cooling powers of the gases, the result of which, it may be proper to give.

Thermometer immersed in carbonic acid gas	cooled in 112 seconds.
—sulphuretted hydrogen, nitrous oxide, and olefiant gas	100+
—com. air, azotic and oxygen gas	100
—nitrous gas	90
—carburet. hydrogen or coal gas	70
—hydrogen	40

" Condensed air cools bodies more rapidly than air of common density; and rarefied air less rapidly, whatever be the kind.—The results of my own experience for common air were as follows:

Density of the air.	*Therm. cools in*
2	85 seconds.
1	100
$\frac{1}{2}$	116
$\frac{1}{4}$	128
$\frac{1}{8}$	140
$\frac{1}{16}$	160
$\frac{1}{32}$	170

"The expenditure of heat by radiation, being the same in hydrogenous gas as in atmospheric air, we may infer, it is the same in every other species of gas; and, therefore, is performed independently of the gas, and is carried on the same in vacuo as in air. Indeed, Mr. Leslie himself admits, that the diminution of the effect consequent upon rarefaction is extremely small, which can scarcely be conceived if air were the medium of radiation.

"The effect of radiation being allowed constant, that of the density of the air may be investigated, and will be found, I believe, to vary nearly or accurately as the cube root of the density *.

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* Dalton, pages 115—120.

SECTION VI.

Boiling or Ebullition.

98. The internal commotion excited in any liquid, by the successive conversion of the lower portions of the fluid into vapour, and their violent effort under this expansive and elastic form, is denominated boiling or ebullition. Though usually it is not necessarily produced by the application of heat; for the removal of pressure from the surface of the fluid, will produce boiling in a liquid, previously in a quiescent state. Thus, if a vessel holding warm water, be placed under the receiver of an air pump, as the exhaustion proceeds and gradually withdraws the pressure, at a certain point of rarefaction boiling takes place. This point, therefore, is not so unchangeable as the melting point, for so far as is yet known, the melting point of each kind of matter is always the same.

99. “ Every particular liquid has a fixed point, at which this boiling commences, (other things being the same,) and this is called the boiling point of the liquid. Thus, water begins to boil when heated to 212°. It is remarkable, that after a liquid has begun to boil, it never becomes any hotter, however strong the fire be to which it is exposed. A strong heat, indeed, makes it boil more rapidly, but does not increase its temperature. This was first observed by Dr. Hooke.

“ The following Table contains the boiling point of a number of liquids.

Bodies.	*Boiling Point.*	*Bodies.*	*Boiling Point.*
“ Ether - - - -	98	Sulphuric acid - -	590
Ammonia - - - -	140	Phosphorus - - -	554
Alcohol - - - -	176	Oil of turpentine -	560
Water - - - - - -	212	Sulphur - - - - -	570
Muriat of lime - -	230	Lintseed oil - - -	600
Nitric acid - - - -	248	Mercury - - - -	660

“ From the experiments of Professor Robison, it appears, that in a vacuum all liquids boil about 145° lower than in the open air, under a pressure of 30 inches of mercury; therefore, water would boil in vacuo at 67°, and alcohol at 34°. In a Papin's digester, the temperature of water may be raised to 300°, or even 400°, without ebullition. But the instant that this great pressure is removed, the boiling commences with prodigious violence *."

100. "The opposite influence of heat and pressure on the constitution of fluids, is well exhibited by a very simple, yet striking experiment. Take a large thin phial, and having warmed it gradually to avoid the risk of cracking the glass, fill it completely with boiling water, cork it tight and expose it to a current of cold air. As the water cools, it necessarily contracts its volume, and leaving an imperfect vacuity below the neck of the phial, it hence becomes, to a considerable degree, relieved from the load of atmospheric pressure; it, therefore, soon begins again to boil, nay, it will boil more briskly the faster it cools; and this singular appearance, so contrary to our usual no-

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* Thomson's Chemistry, vol. 1st, p. 567.

tions, may continue, perhaps, for the space of half an hour, till the water has grown as cold almost as the temperature of the human body *."

101. From this cause of difference of pressure, the boiling point differs with the state of the atmosphere in the same country, and is very different in different countries. Thus, for instance, the boiling point in Britain, under the mean pressure of the atmosphere, is at 212° of Fahrenheit, while at Munich in Bavaria, it is only 209½°, and at Quito in South America, much lower, owing to its great height above the level of the sea, where the pressure of the atmosphere is greatly reduced. Hence, the boiling point has been employed to indicate the heights of places above the level of the sea.

102. "The circumstances which precede or accompany the phenomenon of boiling, are best observed in a thin transparent

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* Ree's Cyclopedia, Art. Boiling.

flask, nearly filled with water, and suspended over a lamp or a charcoal fire. Numerous minute globules are seen collecting from all points towards the sides, and rising in a stream to the surface; occasioned evidently by the discharge of air, which is always in some proportion combined with water. As the heat increases, the liquid particles near the bottom of the flask, suddenly burst into steam, and shoot upwards; but in ascending through the colder mass, they again collapse, stop their progress and seem lost. Such alternate expansions and contractions, by throwing the fluid into a gentle tremour, frequently causes a peculiar sort of singing noise, which is rightly supposed to betoken the approach of actual boiling. This singing is more likely to happen in the case where heat is applied partially; for instance, if a tea-kettle be placed at the side of the fire, since the heat is then more slowly and unequally diffused through the body of the water. But after the whole contents being fully penetrated, are warmed up to the requisite degree of intensity, the steam, as fast as it is formed, ascends continually, and escapes unimpaired through the fluid, which it, therefore, heaves with violent agitation*."

103. When heat is applied to the bottom of a vessel containing water, the heated particles nearest the bottom becomes specifically lighter, and, therefore, mount upward and quickly dispose themselves in horizontal strata, according to their respective degrees of temperature. Thus, a vessel full of water is quickly heated from below. But to communicate heat downwards from this hydrostatic law, is tedious and ineffectual. Not like a bar of iron, which is heated almost equally soon, whether its upper or lower end be thrust into the fire. So difficult is it to heat fluids from above, that Count Rumford inferred, that they were absolute non-conductors of heat. A mass of water heated from below, has the temperatures

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* Ree's Cyclopedia, Art. Boiling.

of the successive strata, reckoning upwards in an accelerating progression, and the centre of the vessel partakes more of the temperature of the bottom, than of the top. The progression is very nearly arithmetical, and Mr. Leslie informs me, that he found it about one degree, for every 10 inches in depth. Thus, when at 212° at the surface, it will be 213°; at 10 inches below, 114°; at 20 inches, &c.

104. " If a vessel containing water be placed over a steady fire, the water will grow continually hotter, till it reaches the limit of boiling, after which the regular accessions of heat, are wholly spent in converting it into steam. The water, therefore, remains at the same pitch of temperature, however fiercely it boils. The only difference is, that with a strong fire it sooner comes to boil, and more quickly boils away. Hence the reason why a vessel full of water, and plunged into the centre of a larger one, which is likewise filled with that fluid, barely acquires the boiling heat, but will never actually boil.

105. " Hence the boiling heat of a deep cauldron, is always rather greater than that of a shallow pan. This excess, we might estimate at nearly one degree of Fahrenheit, for each foot of depth. The heat of ebullition must also rise somewhat higher, if the steam be not allowed to escape as fast as it is generated; for which reason, there may be a slight difference of energy between rapid and slow boiling.

106. " But the position of the boiling point, is likewise modified by the influence of chemical attraction. Thus, sugar, common salt, and other saline substances, have all of them a tendency to fix water, and retard the crisis of its conversion into elastic vapour. Strong brine will not boil until it is heated up several degrees above the ordinary limit. Hence, a vessel containing fresh water, and immersed in another which is filled with brine, will gently boil while the surrounding fluid only simmers. On the other hand, the addition of alcohol, renders water more volatile. In the distilation of spirits, the

fermented liquor in the copper, boils always at a lower temperature, or at some intermediate point between the ebullition of water, and that of alcohol. The spirituous fumes which rise, carry along with them a portion of evapourated water [*]."

Of Steam or Vapour.

107. Elastic fluids, which by cold or pressure are reduced wholly to a liquid state, are denominated *vapour* or *steam*. Such are the elastic fluids arising from water, alcohol, ether, mercury, &c. It is proper to distinguish these elastic fluids from those which have not yet been reduced into a liquid state, by the agency of cold and pressure, which are commonly denominated *gases*.

108. It is stated in Article 44, that bodies by changing their state, also change their specific heat; and hence, when a fluid is converted into vapour, it absorbs a great quantity of heat. Were a great quantity

[*] Ree's Cyclopedia, vol. iv. part 2.

of heat not necessary to the production of vapour, and the body already heated to that temperature, which it cannot pass the smallest possible degree, without being converted into steam; the consequence would be, an explosion of the whole water like gun-powder. But this great quantity of heat enters gradually into the vapour while it is forming, without making it perceptibly hotter to the thermometer, for it is found to be exactly of the same temperature, as the boiling water from which it arose. The water must be raised to a certain temperature, because of that temperature only, it is disposed to absorb heat, and it is not instantly exploded, because in that instant, there cannot be had through the whole mass, a sufficient supply of heat.

On the other hand, it is found, that when the vapour of water is condensed into a liquid, the same great quantity of heat is evolved, and the water into which it is changed, does not become colder to the thermometer by the loss of this great quantity of heat. We are indebted to Dr. Black for this great discovery, which was the origin of his doctrine of *latent heat.* He brought to maturity his speculations on this subject, between the years 1759 and 1763 *. In these inquiries, he was assisted by his pupils, Mr. Watt and Dr. Irvine. Soon after this period, (*viz.* in 1764,) Mr. Watt made his first great improvement on the steam-engine.

109. The combination of a certain quantity of heat in steam, Dr. Black established by the following facts.

The water in a vessel set upon the fire, becomes hotter till it reaches 212°, but afterwards, although heat must be constantly proceeding from the fire, no increase of temperature takes place, the heat must therefore combine with that part of the water which flies off in steam. But the temperature of the steam, is only 212°, therefore the heat combined with it, does not increase the temperature.

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* See Preface to Black's Lectures, p. xxxv.

110. "Mr. Watt put three inches of water into a small copper digester, and screwing on the lid, he left the safety valve open. He then set it on a clear fire of coaks, and after it began to boil and produce steam, he allowed it to remain on the fire half an hour, with the valve open. Then taking it off the fire, he found that an inch of water had boiled away. In the next place, he restored that inch of water, screwed on the lid, and set it on the fire; and as soon as it began to boil, he shut the safety valve, and allowed it to remain on the fire half an hour as before. The temperature of the whole, was many degrees above the boiling point. He took it off the fire and set it upon ashes, and opened the valve a very small matter. The steam rushed out with great violence, making a shrieking noise for about two minutes. When this had ceased, he shut the valve, and allowed all to cool. When he opened it, he found that an inch of water was consumed *."

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* Black's Lectures, vol. i. p. 160.

111. Dr. Black found, in this climate, that it requires 6 times the number of minutes to boil off a small quantity of water, than it takes to bring it to boil.

Hence, 6 times the quantity of heat, which it requires to bring the water to the boiling point, is combined with the steam, and Mr. Watt found from accurate experiments, an exact coincidence between the heat thus combined with the vapour, and that which emerges from it when condensed or re-converted into water. "*And that the heat obtainable* from steam, capable of sustaining the *ordinary pressure of the atmosphere, is not less than* 900° *of Fahrenheit's scale, and that it does not exceed* 950°[*]." Calculations from experiments made by Lavoisier, on the melting of ice, produce a value somewhat higher, of the heat which Dr. Black called latent of steam, "[†] *making it* 1000°, *or perhaps a little more.*

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[*] See Black's Lectures, vol. i. p. 175.

[†] Ibid. p. 175.

Hence, the great scalding power of steam. Hence also, the great heat produced in the refrigitory of a common still.

112. Dr. Black observes, "that it is this great quantity of heat contained in steam, that makes it so powerful and effectual in the business of cookery *." He farther says, "steam is the most effectual carrier of heat that can be conceived, and will deposite it only on such bodies as are colder than boiling water †."

113. Whenever a body hotter than 212° comes in contact with boiling water, it raises its temperature and causes it to expand, but when a body colder than 212° touches it, the heat quits the vapour, and it becomes water, or is condensed.

114. Two English gallons of ice-cold water, dashed in small drops through the capacity of a steam cylinder containing three hogsheads, condenses the vapour which fills it ‡."

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[*] Black's Lectures, p. 179. [†] Ibid. 181. [‡] Ibid. 177.

115. Vapour may be condensed by mechanical compression, as well as by cold.

116. "Mr. Watt has made a great number of experiments, for ascertaining the bulk into which a cubic inch of water is expanded, when it composes the steam, which at the temperature 212°, sustains the pressure of the atmosphere; some of these were direct, by evaporating a known quantity of water, others were more circuitous, deduced from the performance of his engines. The medium result, gave about 1800 cubic inches. We may say that a cubic inch of water, forms a cubic foot of such steam[*]."

117. "As much heat is contained in one gallon of water in the form of steam, as would bring 5½ gallons of ice-cold water, to a boiling heat[†]."

118. From the low temperature at which water boils in vacuo, it occurred to Mr.

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[*] Black's Lectures, vol. i. p. 176.

[†] Black's Lectures, vol. i. p. 185.

Watt, Dr. Black and others, that distilling in vacuo, would be productive of a very great saving of fuel. With this view, Mr. Watt instituted a set of experiments, but says Dr. Black, "The unexpected result of these experiments is, that there is no advantage to be expected in the manufacture of ardent spirits, by distilling *in vacuo.* For we find that the latent heat of the steam, is at least as much increased, as the sensible heat is diminished[*].

119. In the course of a set of experiments, made for a practical purpose on steam, of very different degrees of density, a curious fact, I am informed, was observed, viz. that *the same quantity of water* passed through *the same aperture* in the form of steam, during *the same space of time*, whatever was the degree of density.

120. "The elasticity of all the elastic fluids, into which liquids are converted by heat, increases with the temperature; and the vapour formed when the liquid boils

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[*] Black's Lectures, vol. i. p. 190.

in the open air, possesses an elasticity just equal to that of air, or capable at a medium of balancing a column of mercury, 30 inches high *."

121 " *TABLE of the force of Steam, at different Temperatures from actual experiment, (Betancourt, in Prony's Architecture, Hydraulique.)*

Temperature.	Force in inches of mercury.	Temperature.	Force in inches of mercury.
32°	0	162°	9.07
42	.08	172	11.0
52	.21	182	14.9
62	.38	192	18.7
72	.58	102	23.7
82	.87	212	29.8
92	1.26	222	37.4
102	1.74	232	46.5
112	2.37	242	57.3
122	3.16	252	69.7
132	4.16	262	83.6
142	5.43	272	97.1
152	7.00	282	10.8

" In the 5th volume of ' Memoirs of the Manchester Society,' a table of the force of vapour, for each degree of Fahrenheit, is given by Mr. Dalton; the numbers below

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* Thomson's Chemistry, vol. i. p. 369.

212 degrees, from experiment, and the higher numbers from calculation. Mr. Betancourt, however professes to have obtained all the above results from actual experiment."

122. "*TABLE of the Expansion of a given Bulk of Air, between 32° and 212° Fahrenheit.*"

Tem.	Bulk.	Tem.	Bulk.	Tem.	Bulk.
32°	100000	59°	105616	86°	111232
33	100208	60	105824	87	111440
34	100416	61	106032	88	111648
35	100624	62	106240	89	111856
36	100832	63	106448	90	112064
37	101040	64	106656	91	112272
38	101248	65	106864	92	112486
39	101456	66	107070	93	112688
40	101664	67	107280	94	112896
41	101872	68	107488	95	113104
42	102080	69	107696	96	113312
43	102288	70	107904	97	113520
44	102496	71	108112	98	113728
45	102764	72	108320	99	113936
46	102912	73	108528	100	114144
47	103120	74	108736	110	116224
48	103328	75	108944	120	118304
49	103536	76	109152	130	120384
50	103744	77	109360	140	122464
51	103952	78	109568	150	144544
52	104160	79	109776	160	126624
53	104268	80	109984	170	128704
54	104576	81	110192	180	130784
55	104784	82	110400	190	132864
56	104992	83	110608	200	134944
57	105220	84	110816	210	137024
58	105408	85	111024	212	137440

123. "*TABLE of the Expansion of Liquids by Heat.*"

Tem.	Mercury	Lintseed Oil.	Sulphuric Acid.	Nitric Acid.	Water	Oil of Turpen.	Alcohol.
32°	100000	100000	——	——	——	——	100000
40	100081	——	99752	99514	——	——	100539
50	100183	——	100000	100000	100023	100000	101105
60	100304	——	100279	100486	100091	100460	101688
70	100406	——	100558	100990	100197	100993	102281
80	100508	——	100806	101530	100332	101471	102890
90	100610	——	101054	102088	100694	101931	103517
100	100712	102760	101317	102620	100908	102446	104162
110	100813	——	101540	103196	——	102943	——
120	100915	——	101834	103776	101404	103421	——
130	101017	——	102097	104352	——	103954	——
140	101119	——	102320	105132	——	104573	——
150	101220	——	102614	——	102017	——	——
160	101322	——	102893	——	——	——	——
170	101424	——	103116	——	——	——	——
180	101526	——	103339	——	——	——	——
190	101628	——	103587	——	103617	——	——
200	101730	——	103911	——	——	——	——
212	101835	107250	——	——	104577	——	——

124. "*TABLE of the Expansion of Water by Heat.*"

Temp.	Expansion.	Temp.	Expansion.
42.5°	100000	112.5°	100777
52.5	100030	122.5	101006
62.5	100106	132.5	101220
72.5	100182	142.5	101495
82.5	100273	152.5	101755
92.5	100471	162.5	102040
102.5	100624	172.5	102260*

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* Henry's Chemistry, Appendix, p. xxx. xxxi.

SECTION VII.

Of Ignition.

125. "By ignition (says Mr. Murray) is meant that illumination or emission of light produced in bodies, by exposing them to a high temperature, and which is not accompanied by any other chemical change in them. It is to be distinguished from combustion, a process in which there is also the emission of light and heat. Combustion is always the result, not of mere increase of temperature in the body which suffers it, but of the chemical action of the air, or of a principle which the air contains. A certain class of substances, therefore, denominated Combustible, are alone susceptible of it, and when the process has ceased, the body remains no longer combustible. Ignition is an effect of the operation of caloric alone; it is wholly independent of the air, for by immersing completely any body in melted glass, it is rendered luminous; all bodies, at least all solid and liquid substances, are equally susceptible of it;

and if it has ceased from a reduction of temperature, it may be renewed by the temperature being again raised."

126. "The point of temperature, at which the first stage of ignition takes place, or at which, in common language, bodies arrive at a red heat, appears to be the same in all. Mr. Wedgwood gilded lines, running across a piece of earthen ware, and luted it to the end of a tube, which was placed in a heated crucible; the eye being applied to the other extremity of the tube, no difference of time could be perceived in either the gold or the earthen ware, beginning to shine. No two substances can be more dissimilar; and it may be inferred that all bodies become red-hot at the same temperature. As this can be judged of, only by the illumination, it must, of course, appear various according to circumstances. In a body, therefore, which in the dark appears at a low red heat, the illumination will not be visible in day-light. Sir Isaac Newton, by observing the celerity with which

a body cools, and calculating on the principle which has been already pointed out, (p. 161), concluded, that ignition visible in the dark, corresponds with 635° of Fahrenheit's scale, full red heat with 752°; and ignition visible in day-light, with above 1000°. Dr. Irvine having found that quicksilver boils at 672°, and having observed, that boiling mercury did not appear at all luminous in the dark, it necessarily followed, that the point of ignition must be higher than Newton had supposed it to be. He had farther found, that when equal *bulks* of iron and water at different temperatures are mixed together, the resulting temperature is nearly the *mean*, and he applied this method to determine the point of ignition; the result is not precisely known; but the heat of a common coal fire, he found to be 790° or 796° *. Mr. Wedgwood by the expansion of the piece of silver, measured by a gage of baked clay, by which he endeavoured to connect his thermometer with

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* Chemical Essays, p. 83.

Fahrenheit's, as has been already explained, fixed the point of ignition visible in the dark, at —1 of his scale, which corresponds with 947° of Fahrenheit; and ignition in day-light, he placed at the commencement of his scale, or 1077°. This differs from the preceding results; and as it is probable that the silver would suffer an increasing expansion, this might cause the temperature to appear higher than it actually was, and hence, have given the point of ignition too high. It is probably not far from 800° of Fahrenheit.

127. " By raising the temperature, the illumination becomes brighter, and the red heat acquires a mixture of yellow rays. At length, by increasing the heat, we have the due proportion of coloured rays, which forms perfectly white light. This is the highest state of ignition, or any farther rise of temperature produces no apparent change.

128. " Ignition continues undiminished, as long as the temperature is kept up, unless the heat be such as to volatilise or alter the constitution of the ignited body.

129. " The aëriform fluids are not brought into a state of illumination by heat. This was observed by Dr. Fordyce, in the example of the vapour, at the end of the flame of a blow-pipe, which though itself not visibly luminous at its extremity, will, if applied to glass, raise it to a white heat *. The fact was afterwards also established by Mr. Wedgwood. Air was forced to pass through an earthen tube, in a state of ignition, and was conducted into a globular vessel, from which, by an opening in the top, it was allowed to escape; while by another opening in the side, closed by a piece of glass, the eye could be directed into the inside of the globe. On looking into it, the air which had passed through the ignited tube was

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* Phil. Trans. vol. lxvi. p. 504.

not luminous; but if a solid body, as a piece of gold, was suspended in it, this became luminous *. This is probably owing to the tenuity of aëriform fluids, whence they present too few points in a given space, to project a quantity of light sufficient to excite vision.

130. " The phenomena of ignition are produced, not only by the application of heat, but likewise by friction and attrition. When a piece of steel is struck against a flint, small particles of the metal are detached, which are at a red heat. Or if various hard minerals be made to act strongly against each other, they give out light. By applying, for example, quartz or agate to the circumference of a wheel of fine grit, revolving at a moderate rate; Mr. Wedgwood observed, that the substance applied became brightly red even in day-light, at the touching part; if the wheel revolved at a quicker rate, the part in contact emitted a

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* Phil. Trans. vol. lxvi. p. 504, 1792.

pure white light; and in both cases, glowing sparks were continually emitted, some of which were not extinguished before they had passed twelve or fourteen inches through the air. They exploded gunpowder and inflammable air; and burnt the skin, a sufficient proof that they were not merely luminous or phosphorescent, but ignited, or at a red heat. In the same mode, glass and porcelain were raised to a red heat. These appearances from attrition, are probably to be ascribed to the heat which is excited, rising sufficiently high to extricate their light, as the same bodies become luminous when directly heated, and as the same appearances are not produced in substances which are soft, these not having their temperature raised by attrition[*]."

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[*] Murray's Chemistry, vol. i. p. 253—257. Phil. Trans. for 1792, p. 39.

Description of Plate 1.

131. *Fig.* 1, is a comparative view of Fahrenheit's scale, and Mr. Dalton's new divisions of the scale of the mercurial thermometer. The interval from freezing to boiling water, is 180° on both scales, and the extremes are numbered 32° and 212° respectively. "There are no other points of temperature in which the two scales can agree[*]."

Fig. 2, represents Reaumeur's scale, as also that of the centigrade, (Art. 10, 11).

Fig. 3, shows the scale proposed by Mr. Murray, (Art. 12).

Fig. 4, represents the connection of the mercurial thermometer, with that of Mr. Wedgwood, (Art. 26).

Fig. 5, "is the logarithmic curve, the ordinates of which, are erected at equal intervals, and diminish progressively by the ratio $\frac{1}{2}$. The intervals of the absciss or base of the curve, represent equal intervals of temperature, (25° for steam or aqueous vapour, and 34° for ethereal vapour,) the ordinates represent inches of mercury, the weight of which is equal to the force of steam at the temperature. Thus the force of steam at 212°, and of ethereal vapour at 110°, new scale, is equal to 30 inches of mercury; at 187° the force of steam is half as much, or 15 inches, and at 76°, that of ethereal vapour is also 15 inches, &c.[†]" (Art. 24.)

Fig. 6, represents Mr. Leslie's differential thermometer, (Art. 80).

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[*] Dalton's Chem. Phil. p. 217.

[†] Dalton's Chem. Phil. p. 218.

END OF PART FIRST.

Part Second.

ON

HEATING

MILLS, DWELLING HOUSES, AND PUBLIC BUILDINGS,

BY STEAM.

SECTION I.

132. IT may be proper, in general, to mention, that the steam is usually generated in a boiler similar to those employed for steam-engines, and having similar apparatus for supplying it with water. The boiler is placed in any convenient

situation, in or near the building to be warmed; from it the steam is conveyed in pipes, through the various rooms where heat is required.

Of the proportionate size of Boilers.

133. The proportionate size of boilers is a point of considerable practical importance. It has been ascertained, that *one cubic foot* of boiler will heat about *two thousand cubic feet* of space, in a cotton mill[*]; (See Notes A. and B.) and if we reckon *twenty-five*[†] cubic feet for every *horse's power*[‡] in a steam-engine boiler; of course, such a boiler of a steam-engine, would be capable of warming *fifty thousand cubic feet* of space for every *horse's power* of the engine.

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[*] In cotton mills the temperature is in general from 70 to 80 degrees of Fahrenheit.

[†] I am aware that the quantity of steam, which a boiler will produce, depends much more on the surface applied to the fire, than on its cubical contents: but I here allude to boilers of the form at present most generally used in steam-engines. Twenty-five cubic feet, however, is an ample allowance. See Art. 64.

[‡] Respecting the resistance to which a horse's power is estimated by mechanics, as being equal. See my "Essay on the Teeth of Wheels."

134. A separate boiler ought, however, to be considerably larger than the extra size allowed on a boiler, used for the joint purpose of a steam-engine and warming a mill; to avoid the inequality of heat incident to a boiler working to the full extent of its capacity.

135. Having ascertained the size of the boiler, the fuel may be easily estimated by the following rule, which I believe Messrs. Boulton and Watt adopt with respect to their steam-engines: *That is, about* 14 *lbs. per hour of good Newcastle coal, for each horse's power.* It may be proper, however, in general, to make a large additional allowance for defects in furnaces, and inattention in the attendants. See Art. 59—70.

SECTION II.

Of the proportion of Steam-pipe required to warm a given space.

136. In cotton mills, it has been ascertained, that, in most cases, *one superficial foot of exterior surface of steam-pipe, will warm two hundred cubic feet of space.* A larger allowance, however, of steam-pipe is usually given. Mr. H. Houldsworth, in the mill at Anderston, has about *one hundred and seventy-nine* cubic feet of space, to one superficial foot of external surface of steam-pipe. Messrs. Kennedy and Watt at Johnston, allow about *one hundred and sixty-eight feet.* At Catrine, *about two hundred.* But the temperature in those mills, is much greater than is required for common purposes, being from 70 to 85 degrees of Fahrenheit. (See Note B.) Mr. Macnaught has lately warmed a small chapel at Port-Glasgow, to a comfortable temperature, by *one foot* surface of steam-pipe to *four hundred cubic feet of space.*

137. In the above examples, the steam used, is about the strength usually employed in Messrs. Boulton and Watt's engines *. Stronger steam would, no doubt, emit more heat from a given surface of steam-pipe, but it would be difficult in that case, to keep the joints steam-tight.

138. The nature of the building ought first to be considered, whether much exposed to cold winds, whether it be closely finished, whether there be much wall, in proportion to its capacity, whether the temperature required, be moderate or high. These circumstances being taken into consideration, a judgement may be formed of the proportion of steam-pipes, from what has been ascertained to be sufficient in existing cases. (See Note B.)

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* That is, the safety-valve on the boiler to be loaded to about 2½ lib. to the square inch.

SECTION III.

Of the Substance, and Surface of the Steam-pipe.

139. IN order to save expence, pipes of tin-plate have been tried, in preference to cast-iron. It was supposed too, that from its thinness, it would emit the heat more rapidly than cast-iron. Upon the same idea, thin copper pipes[*] were also tried Contrary to expectation, however, it was soon found, that the same surface of cast-iron gave out much more heat, than either the tin-plate or copper.

140. Mr. H. Houldsworth made some experiments to ascertain the difference between tin-plate and cast-iron, with respect to their effects in emitting heat; and found, by measuring the quantity of steam condensed in equal lengths of pipe, or, in other

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[*] Copper tubes when heated, emit a disagreeable smell, which it is probable is as unwholesome as it is unpleasant. Lord Landsdown at great expence, applied them under the floor of his Library with a view to having it warmed by steam, but whether from this cause or from the arrangement being improper, I knew not, but the plan was abandoned.

words, by measuring the water of condensation, (Art. 45,) that, taking the effect of tin-plate in emitting heat as *one*, the effect of cast-iron was equal to *two and a half*[*].

141. One of the apartments of the Adelphi cotton-mill, Glasgow, which had steam-pipes made of tin-plate, was not found so warm as was required. When this occurred, my attention was directed to some of Professor Leslie's experiments on heat, this induced me to try the effect of painting them black; the increase of heat, from painting, was great beyond expectation.

142. This trial led me to suspect that the greater effect of cast-iron arose, not from the nature of the substance, but from the

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[*] These experiments were made on tin-plate tubes, 5½ inches external diameter, condensed 6 lbs. of water in the time that those of cast-iron 7¼ external diameter, and of equal length condensed 22 lbs.

Inches *Lib.* *Inches* *Lib.*
as 5¼. : 6 : : 7¼. = 8. 2. the quantity proportionate to the diameter of the pipe, *two and a half times*, which amounts to 20½ lib. but the real quantity condensed we saw was 22 lib. It is proper to observe, that the tin-plate tubes were considerably tarnished by being about 2 years in use, (Art. 90).

colour and nature of the surface. I therefore had some experiments made to ascertain this fact[*]. The results were sufficient for my purpose at the time; but it were to be wished, that the subject might be examined by others with still greater accuracy. It appeared, that when equally dark in colour, and when the surface was equally rough, tin-plate emitted heat as rapidly as cast-iron[†].

143. Cast-iron, however, has been found much more durable, and convenient, in its application, than other metals, which have been tried. And it appears, when durability is required, that it is the only substance which seems properly applicable to the purpose. Indeed it has been adopted in most of the late cases of warming

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[*] These experiments were made somewhat in the manner of those of Professor Leslie.

There was a canister having four equal sides, three of which were of tin-plate, and one of cast-iron. This canister was filled with hot water, and an air thermometer indicated the temperature.

[†] Whether this effect proceeded from the joint operation of colour and roughness of surface, or from roughness alone, my experiments did not ascertain. Mr. Houldsworth tried cast-iron pipes painted various colours, but found no difference of heat. (Art. 90).

by steam ‡. Some, nevertheless, still prefer tin-plate pipes, as being cheaper, more speedily erected, and, when painted, as effective in emitting heat.

144. With regard to the thickness of the pipes, I do not suppose that this is to be limited but by expence; for a thick pipe, acting as a reservoir of heat, preserves a more uniform temperature than a thin one. It is usual, however, in order to save expence, to make them as thin as they can be conveniently cast, which may be from a half to three-fourths of an inch. Professor Leslie obligingly suggested to me, that whenever the steam tubes come in contact with the walls of a building, in order to save the heat, a piece of tin-plate should be interposed, (Art. 90.)

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‡ Lead is a very improper material for conveying steam, it soon cracks, and becomes no longer steam-tight. When steam-pipes are made of tin-plate, or any other thin metal, it is necessary to have valves opening inwards, to allow the air to rush in, should a vacuum take place in the pipes. Where due attention has not been paid to this precaution, the pipes have often suddenly collapsed. In cast-iron pipes such valves are less necessary.

SECTION IV.

General Observations respecting the Direction and Arrangement of the Pipes.

145. In the arrangement of steam-pipes, one of the greatest difficulties which occurs, proceeds from the expansion of the metal. —When the pipes are single, this is easily overcome; but where pipes are connected at various angles, the principal difficulty is, at the same time, to preserve the joints, and give liberty for expansion.

146. To give some idea of the effect of the heat of steam, in producing expansion, I may mention, that a copper steam-pipe 160 feet long, was two inches longer when filled with steam, than when cool; and that *in practice, the expansion of steam-pipes of cast-iron may be taken at about one-tenth of an inch, in ten feet of length.*

147. " Brass expands about one hundred thousandth of its length, for each degree of Fahrenheit; copper and gold a little less;

silver somewhat more; iron and steel, about two-thirds as much; tin, one-third more; and lead and zinc about half as much more *." (See Art. 28, 37.)

148. Count Rumford, in warming the Lecture-Room of the Royal Institution, by steam, used drums of thin copper at the terminations of the pipes; the heads of these drums were about three feet in diameter, and yielded to the expansion of the pipes. This plan, however, in most situations, would require too much space, and be attended with too much expence.

149. When a straight pipe, filled with steam, stands in a vertical position, it is equally heated all round, and expanding equally, continues to be straight, but when it lies in a horizontal direction, the upper side becomes the hottest, and expanding more than the lower, bends the pipe, which in some cases endangers the joints. Mr. Dalton, in a letter of the 14th June, 1808,

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* Young's Nat. Phil. vol. i. p. 643.

with which he favoured me, respecting my pamphlet on warming buildings by steam, says, "I do not feel convinced of the advantages of vertical pipes, they must diffuse less heat, having a hot current of air sweeping them. Could not the bending of the horizontal pipes, by unequal temperature, be prevented by soldering a small tin-plate to the upper surface of the pipe. This would take the excess of heat from the upper surface and dissipate it."

Since publishing the pamphlet above alluded to, experience and reflection have convinced me of the justice of Mr. Dalton's observations, and I find it is only in case of joints made with flanches of great diameter, that there is any danger of their breaking in a horizontal position from unequal expansion *. When air is heated, becoming more rare, it has a tendency to

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* In a mill which Mr. Houldsworth has heated by very thin cast-iron steam pipes, he found that several of those which were vertical gave way in the thimble joints, while all those which were horizontal remained good. The reason of this difference probably is, that the horizontal pipes are more gradually heated, by the water of condensation going before the steam.

ascend, horizontal pipes should, therefore, when practicable be placed near the floor, (Art. 89).

150. In arranging steam-pipes, two points require considerable attention: *First*, conveniently to expel the air; and, *secondly*, to take off the water resulting from the condensation of the steam; which, to avoid circumlocution, we shall call *the water of condensation.*

In regard to the *first* point, the steam, in entering the pipes, may be considered as a kind of a piston, driving the air before it: for the steam and air mix very imperfectly in the pipes, and there appears almost a distinct line between their surfaces. This principle should therefore be kept in view, in fixing upon the place of the opening for allowing the air to escape, while the pipes are filling. One or more passages is likewise necessary, after the pipes are filled, in order to allow a small portion of steam constantly to escape, to keep up the heat in the pipes. For if this be not done, air will accumulate, and occupy the place of the steam.

151. With regard to the *second* point, when it can conveniently be done, it is better to make *the water of condensation*, to run in the same direction with the steam. Indeed, in a horizontal pipe, the steam will drive the water before it, and will do so when the internal diameter does not exceed 2½ inches; even if the pipe should have a considerable acclivity. Great care, however, should be taken, to prevent the water from lodging in any part of the pipes. From want of due attention to this circumstance, accidents have not unfrequently happened. The water remaining in the pipes after they become cool, keeps one part of them cold. The consequence is, that next time the steam is let into the pipes, the regular expansion is prevented, some part of the pipe cracks, and a violent explosion takes place, racking the joints, to a considerable distance in every direction, from the place of explosion.

152. In most cases, it is attended with least labour and expence, to place the pipes in the horizontal direction.

SECTION V.

Of the Methods of Connecting the Steam-Pipes.

Method 1. *Figure* 1.

153. Represents the method of connecting pipes by means of *flanches*. A and B are the pipes, the projecting parts CD, are called the *flanches*.

The junctures are secured by interposing rope-yarns, or some other pliant substance, and iron-cement, and then screwing up the whole by means of the screw-bolts EE, &c. In all cases where bolts are used in steam-pipes, they ought to be carefully lapped with rope-yarn.

Observations.

When the pipes are horizontal, from inequality of expansion, the *flanches* are liable to be broken, or at least to leak at the bolt holes. For vertical pipes, they may often be applied with advantage. This seems to have been one of the oldest methods in use, for the purpose of connecting cast-iron pipes, (See ~~Belidores Arch. Hydraulique~~).

[illegible]

[illegible]

N. B. All the observations which are here made on the modes of connecting pipes, relate to *the conveying of steam* only.

Method 2. Figure 2.

154. Represents a spigot and facet joint. The juncture is secured by iron-cement, to fill the space between the spigot AB, and the facet CD.

Observations.

Spigot and facet joints do very well in most cases, but there have been instances of facets bursting from the greater expansion of the spigots. The risk of this accident is increased, by increasing the space for the cement.

Method 3. Figure 3.

155. This figure represents a thimble joint, which is secured in a similar manner with method 2.

Observations.

This is a very convenient mode of joining steam-tubes. If a thimble burst, it is easily renewed, and any one pipe may be moved without disturbing the rest, which cannot be done by method 2. Thimbles are often used also to repair spigot and facet pipes; when the facets break, sometimes it is convenient to make the thimbles in two parts, as represented by No. 4. *Fig.* 3. It occurs to me, that it would be an improvement to make the thimbles of plate-iron, leaving but a small space for the cement. On this plan, the expansion would be more equal, and the risk of the joint being injured, of course, much lessened.

Method 4. *Figure* 4.

156. Represents a mode of connecting spigot and facet pipes, where they are to have a turn or angle.

Observations.

This method is simple and convenient, when the place where the turn is required is previously known, and the pipes cast accordingly.

Method 5. Figure 5.

157. Represents what is called the saddle joint, used for taking off a branch The branch has a piece AB formed on its end, which fits round one-half of the outside of the pipe from which it is to spring. CD is called the saddle which fits round the other half of the pipe. Two screwed hoops FG FG, embrace the saddle, and the part AB, and cement being interposed, they serve to secure the whole.

Observations.

By this method a branch may be formed on any part of a pipe, by cutting a hole there, and applying the joint to that place. This easy method of applying a branch is often of great use in practice, and the hoops make it very secure, without the disadvantage of bolt-holes in the cast-iron.

158. Where there is much risk of the inequality of expansion, the joints at certain places, should be secured by a soft stuffing of hemp or cotton, and tallow; but in most

cases, the joints may be made with iron cement [*]. Lead has been tried for making the joints, instead of iron cement, though easy of repair, the lead soon gets loose by alternate expansion and contraction.

159. At Butterly Iron-Works, Derbyshire, there is a very good plan of a joint, which has been in use about 7 years, and during the whole of that period, it has continued tight and required no repair. It operates for the expansion of a pipe conveying steam about 40 yards, which makes it yield backward and forward about ¾ of an inch. The two adjoining ends of the pipes A and B, are turned true on the outside, and have a thimble CDEF, with tin interposed between it and the pipe which being less liable to expansion than lead, has continued durable, and still fits well to the turned parts of the pipe, which work in it like a piston in a cylinder, (See Fig. 6).

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[*] This cement is composed of 40 lbs. iron borings, 1 do. salamoniac, ½ do. sulphur, well mixed together, and beaten like putty.

Much sulphur is hurtful, rendering the composition brittle. When, therefore, a considerable time can be allowed for the cement to settle in the joints, before the steam is applied, a smaller proportion of sulphur than the above, may with advantage be adopted.

Method 6. *Figure* 7.

160. Represents the method of making joints, on vertical pipes, when they are used as pillars for supporting floors. The ends are turned to fit each other, and iron cement is interposed. The weight is then sufficient to secure the joint.

Observation.

No. 2. is only used when there is not room for the projecting part on the outside as in No. 1. which is preferable when circumstances will permit.

161. Before putting up any of the steam-pipes, they should be proved to be solid, by the usual process of forcing water into them.

SECTION VI.

Description of Boiler for generating Steam, with Apparatus for supplying it with Water, regulating the Damper, &c.

162. ABCD Fig. 8. represents the boiler which is kept in a state of ebullition, by means of a furnace and flues, as represented in the figure, but I shall not *at present* enter upon the subject of what is called *hanging* of boilers.

Apparatus for supplying Water.

163. E the float which is usually made of stone, but which has a balance-weight, F, so as to make it act as if it were specifically lighter than water. The float E swims on the surface of the water in the boiler, and by means of the wire EG is connected with the lever GH, from which by another wire IK, there is a communication with the valve K. The valve K is situated in the bottom of a small cistern, which is constantly supplied with water by a pump, or otherwise.

When there is a sufficiency of water in the boiler, the valve K remains shut. But suppose the water in the boiler to fall too low, we shall see what takes place. The float E sinking along with the water, by means of the intermediate parts already described, opens the valve K, and allows the water to get through the valve, and down the pipe KLMN into the boiler, until it again raise the surface of the water, and along with it the float E, which, of course, again shuts the valve K, and thus prevents the further admission of water, until it be again required.

Apparatus for Regulating the Damper.

164. Connected with the pipe KLMN is another, but smaller pipe, MNOP, which reaches, usually, within about 12 inches of the bottom of the boiler.

In the pipe KLMNO there is a hollow float-vessel Q, which is suspended by a chain QR from the pulley S. The vessel Q has liberty to rise and fall freely in the pipe, which liberty also allows the water from the feeding-valve K, to escape past its sides, and so into the boiler.

From another pulley T, the damper W is suspended by another chain TW.

While the fire is not too violent, the float-vessel Q remains at the bottom of the pipe KLMN, but suppose the fire to become too strong, then the steam pressing on the surface of the water in the boiler, forces part of it up the pipe MNOP, which raises the vessel Q, and by means of the intermediate parts already described, depresses the damper W, and so by narrowing the passage for the smoke, checks the draught of the furnace, and, of course, damps the fire.

Safety Valves.

168. In order to prevent accidents, there is a valve *a* which opens by the elasticity of the steam, when it exceeds about 2½ lbs. upon the square inch, *a b* is the pipe which conveys the steam into the building. There are also valves placed on or near the

boiler, which open inwards, to prevent accidents from a partial vacuum taking place in the pipes, or boiler.

Guage-Cocks.

166. *c* and *d* are the guage-cocks. *c* communicates with a short pipe, which terminates a little *above* the proper surface of the water. There is another pipe from *d*, which terminates a little *below* that level. Accordingly, as water or as steam forces through either of those cocks, the keeper of the boiler is enabled to judge of the height of the water within the boiler. Besides the guage-cocks, a glass tube is sometimes used, which shows to the eye, the height of the water in the boiler. The tube is fixed on the outside of the building, and communicates with the boiler, by means of two pipes, the one under the proper level of the surface of the water and the other above it.

Contrivances to give an Alarm when the Water in the Boiler falls too Low.

167. For this purpose, is sometimes used a pipe of about 2½ inches diameter, reach-

ing from a little way below the proper level of the surface of the water, to about 9 feet above the upper part of it. Its upper termination is like an organ pipe. Should the water, therefore, fall too low, the steam rushes through the pipe, and makes a noise which alarms the whole neighbourhood, and so may prevent the bottom of the boiler from being burnt out, an accident, by no means unfrequent. Other means have also been proposed for the same purpose, such, for instance, as working a stop-cock by a float, which, when the water falls too low, would allow the steam to blow into a Boatswain's whistle.

SECTION VII.

Syphons.

168. It may be here observed, in general, with respect to syphons, 1st, That they should have a pressure of water, of at least 9 feet in them, in order to prevent the water from being thrown out of them, which would be the case, with a small pressure, more particularly as the water is liable to sudden oscillations. 2d, That they should be wide enough to discharge the water with ease. 3d, That they should be in situations protected from the cold, there having been instances of their being rendered ineffectual from the water freezing in them. A stop-cock for letting off the air is commonly placed between the steam-pipes and the syphon. Sometimes there is a small hole (the size of a pin) made in that part of the stop-cock which is nearest the steam-tubes, in order that there may always be a small qnantity of steam escaping to prevent accumulation of air, in any part of the pipes.

It frequently occurs, that proper depth cannot conveniently be obtained for a syphon. In that case, a valve to open by a float-ball, has been applied. The valve remains shut, until the *water of condensation* begins to accumulate, which raises a hollow copper ball attached to the top of the valve, and allows the water to escape. A syphon is, however, preferable wherever depth for it can be obtained, being much more simple, and less liable to be put out of order.

ABC, Fig. 9. represents a *syphon*. *The water of condensation*, which accumulates in the steam-pipe CD, escapes at A. E is the *stop-cock* for allowing the air to escape by the pipe EF. EG is a smaller pipe, which communicates with a very small hole between the *stop-cock* and the steam-

I omitted to mention in its proper place, what is called the *steam-gauge*. It is a small iron syphon containing some inches of mercury in its bended part (which is downward). The one leg of the syphon communicates with the *boiler*, or some part of the *steam-pipes*. The other leg communicates with the atmosphere, and has a small wooden rod in it, which being raised or depressed, indicates the different degrees of density of the steam. The steam-gauge is represented by *tw*, Fig. 8, Plate 2.

pipe CD, and allows a very small quantity of steam constantly to escape, as was mentioned in this Section.

A syphon of this description, with a wide bore, may often with advantage be used as a *safety-valve* to a boiler. It might also be used for allowing the *water of condensation* to escape, in situations where there is not sufficient depth for a syphon, containing water only.

Through inadvertency, the following Note was omitted, which should have been placed in page 172.——A syphon, having its bended part downwards, allows the water to escape, while its pressure confines the steam. This contrivance, or something on the same principle, is very commonly adopted.

SECTION VIII.

Description of some Cases, of the Direction and Arrangement of Steam-pipes in Actual Use *.

169. Having made some general observations, respecting the direction and arrangement of steam-pipes,—having considered the various methods of connecting them, and having described the boiler and its apparatus, it may now be proper to notice the direction and arrangement of the pipes, in several cases, in actual use, and, as we proceed, to make some observations on each of these arrangements.

Arrangement I. for Heating a Cotton-Mill.

170. A horizontal pipe conveys the steam from the boiler into the mill, connected with a vertical pipe reaching nearly to the ceiling of the uppermost room.

In each floor there is a horizontal pipe, placed about 2 feet below the ceiling, and each horizontal pipe has a stop-cock [*], where it branches off from the vertical pipe. A syphon for conveying off part of the water of condensation, is placed at the bottom of the vertical pipe.

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* See also Note B, at the end of this Essay.

Observations.

At the Catrine cotton-works, where this arrangement is adopted, the pipes have their declivity towards the boiler, so that the water of condensation, runs in an opposite direction to the passage of the steam. A great proportion of it, finds its way back to the feeding apparatus, by a small pipe; the rest of it, is carried off by the syphon.

At the further end of each horizontal pipe, there is a small safety-valve opening inwards, to prevent accidents from a vacuum taking place within the pipes. That valve also serves to allow the air to escape, while the pipes are filling with steam. No practical disadvantage is experienced, I am informed, from all the steam which escapes on that occasion.

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[*] These stop-cocks at the Catrine works, are common inch-and-half brass cocks.

171. With horizontal pipes, it is very common to have a smaller pipe, with a stop-cock from each, going through the wall, to allow the air to escape; but from what has been experienced at Catrine, this precaution does not seem to be absolutely necessary, nor yet (as is also common) to take off the water of condensation from the further ends of the pipes, in which case the pipes incline in that direction.

172. I, however, think although less simple, it is a more perfect arrangement to take off the water of condensation from the further end of each horizontal pipe, more particularly when such pipes are of great length. The water of condensation going before the steam, serves to warm the lower part of the pipe, and make the expansion of the upper and under parts of it more equal, when the steam comes forward. At Catrine, the tin-plate pipes, have

been in use several years, and proprietors think them sufficiently durable. It is not, however, the general opinion of those who have tried both tin-plate and cast-iron; but it is well worthy consideration, for pipes of tin-plate, are much more speedily erected, and are cheaper at the ordinary prices, in the proportion of about 7 to 17. One defect in this arrangement, as commonly executed, is having the pipes too high above the floors; but they might be placed near the floor, and yet arranged on the same general principle. This arrangement possesses a very considerable advantage, for some purposes, over that about to be described, viz. that each floor may be heated separately.

Arrangement II. for Heating a Cotton-Mill.

173. The steam from the boiler, in this arrangement, ascends in the vertical pipe, to the highest story, where going along the floor horizontally, to the further end, it descends in a short vertical pipe to the story below, where it is again carried along

horizontally, and thus is made to descend until it arrives at the bottom. There the water proceeding from condensation, is allowed to run off by a syphon, and the air is allowed to escape by a stop-cock, near the same place.

Observations.

This arrangement is exceedingly simple, and is that adopted by Mr. T. Houldsworth, in his cotton-mill (consisting of 8 stories) at Manchester. Although the house be 42 feet wide, and the pipes on one side, the heat is found sufficiently uniform, in every part of the floors, for practice, and, in that situation, it occupies little space.

It is a disadvantage in this arrangement, that no part of the building can be heated separately from the rest. But in a cotton-mill, this is not attended with much inconvenience.

Messrs. Todd & Stevenson, at Glasgow, have their mill heated by a similar arrangement, but the pipes are of tin-plate, and were fitted up about the year 1793.

174. In arranging the steam-pipes for Milgavie cotton-works, a similar mode was followed. There, the steam-pipes require about two hours in the morning, before they are completely filled with steam.

Arrangement III. for Heating a Cotton-Mill.

175. In this arrangement, the principal part of the tubes are vertical, and serve to support the floor.

176. A horizontal pipe conducts the steam from the boiler to the nearest vertical pipe, and thence it is conducted by the horizontal pipe, to the top of the new vertical pipe, and so on, alternately ascending one pipe, and descending the next. Below, it passes from one vertical tube to another by the wider pipes. There are smaller pipes to carry off the water of condensation, and being placed just below the level of the under parts of the larger ones,

they are kept always full of water, so as to prevent the steam from passing through them. At the further end, the water of condensation is let off by a syphon, and the air by a cock or valve, which, in order to allow the air to escape freely, should be as large as the diameter of the steam-pipes. If the number of pillars be not even, then the air-valve should be at the top of the last vertical pipe.

Observations.

This mode saves the expense of pillars, for supporting the floors, but every one of experience, knows the disadvantage of having any apparatus or piece of machinery, so constructed as that, when any particular part of it is out of order, it cannot be repaired without deranging the whole system.

There are many mills, however, fitted up on this plan, which give satisfaction to the proprietors.

Messrs. Forbes, Low, & Co's. great mill, which is heated in this way, at Aberdeen, requires about three quarters of an hour to let off the air and fill the tubes with steam. Messrs. William King & Co.'s mill at Johnston, is also on that plan. There the steam passes through about 400 feet of tubes, in 15 or 20 minutes. The tubes should be equally wide throughout, in order that they may fill with greater facility. (See Note B).

Dwelling-Houses.

177. There are yet but few instances of dwelling-houses heated by steam, nor, perhaps, would it be eligible to heat small houses separately by it, on account of the trouble it would require to keep a small boiler regularly supplied with water and fuel. But where steam can be obtained from a steam-engine boiler, or where a number of neighbouring buildings could be supplied from one boiler, much might be saved in attendance and fuel, as well as cost of apparatus. In cases where single buildings are large, such as Inns, Hotels, &c. steam might be applied with peculiar advantage in heating the stair-cases, pas-

sages, bed-rooms, &c. An eating-room heated by an open fire only, is often unpleasantly cold to those who sit near the door, while it is oppressively warm to those who sit near the fire. This inconvenience might be remedied by the use of steam. A very small open fire in that case, would be sufficient to give a cheerful appearance to the room. The particular arrangements of the apparatus proper for dwelling-houses, must depend much on local circumstances. As the steam may be admitted into vessels of almost any form, the ornamental may be combined with the useful. I am at present, engaged in some experiments, with a view to simplify such arrangements, but am not yet ready to lay the result before the public.

178. Mr. Lee of Manchester has his dwelling-house heated by steam, conveyed under ground from the boiler of a steam-engine. The stair-case, lobby, and passages, are heated by means of a steam cylinder, placed vertically in the sunk story. The

steam cylinder is surrounded by a casing of brick-work, leaving a space of about two and a half inches all round, and having openings below to admit air. This casing is surrounded at some little distance, by another cylindrical wall, forming what we may call the well. The coldest air being the heaviest, falls to the bottom of the well, and enters by the holes below into contact with the cylinder, where, becoming heated and specifically lighter, it ascends. This circulation of the same air, in a very short time, makes the stair-case, &c. comfortably warm. There is a valve to regulate the admission of the steam into the cylinder. There is also another valve on the top of the casing of brick-work, to regulate the transmission of the heated air. It generally soon becomes so warm, that it is necessary to shut one or other of these valves.

The dining-room is heated by means of two ornamental cast-iron vases filled with steam, and the bed-rooms by steam-pipes of the same material.

It may not be improper to mention, that the house is lighted, in a very elegant manner, by coal gas.

179. In answer to some inquiries which I made respecting heating of an inn at Johnston, by steam, Mr. M'Naught obligingly sent me the following letter:

Johnston, 7th Sept. 1809.

DEAR SIR,

In compliance with your request, I now send you a description of the Black Bull Inn, as it is heated with steam.—There is a boiler fitted up in the ordinary way, except the furnace mouth, which is made like a hopper, in order to hold a considerable quantity of coal-gum * or dross, and prevents frequent attention to the fire, as there may be put in as much at a time as will serve at least half a day, and will need only to be stirred a little with the pocker now and then. The under flat is heated with triangular pipes, to imitate a cornice, the place of which they occupy in one side of all the rooms; from the metal cornices, a pipe is taken to the upper rooms into a sort of chest, which stands upon short feet similar to a desk, and freely admits air below it. They are ornamented in front similar to carron-grates, &c. in some of the rooms there are two, in others only one, of these chests, according to the size of the rooms. As they are yet hardly finished, and have been tried only a few days, little can be said as to the effect. Considering the doors being so frequently opened, &c. a large portion of heated surface has been allowed, about 1 foot to 100. It seems to me, that the house will be too warm, but it is impossible to judge accurately till cold weather commences.

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* Culm.

The reason for keeping the under pipes so high as the cornice, was to get the condensed water back into the boiler, as there is no regular supply, what they have is got from the roof, and kept in a number of casks supported in a row above the boiler. And by using the hot water from the pipes, there is only the waste of evaporation for to keep up. There is a steam kitchen connected with the boiler, in a pretty advanced state.

Among other advantages, a dinner or plates, &c. may be kept warm by setting them on the top of the chests, and placing a cover over them. It will also save a servant, during winter at least, and as there is more power in the boiler than necessary, some of the neighbours have been treating to be heated from it.—This you will see will become common in a short time. I am,

DEAR SIR,

Yours, &c.

Public Buildings.

180. In the year 1801, Count Rumford, arranged the apparatus, for heating the Great Lecture-room of the Royal Institution by steam, in the following manner:

The steam is generated in a boiler on the ground floor, and is conveyed by a copper pipe into the Lecture-room. There, it divides into two branches, and passes horizontally under the seats.

In order to counteract the expansion of the pipes, there is a drum of thin copper, placed in the middle of each tube. The water of condensation is carried off from the lower part of each drum by small tubes, and conveyed back to the boiler.

The general arrangement here seems good. The lower part of the room being heated, the other parts must of course, be sufficiently warm. The plan of the expansion drums, although ingenious, is objectionable on account of expense, as well as on account of their occupying a very large space.

We are yet much in want of examples of heating public buildings by steam, but it is highly probable that it will soon become more general. The mode in which Mr. Lee heats his stair-case, might perhaps be applicable with advantage in many cases of public buildings. Much of what is said respecting dwelling-houses may be applied here.

Baths.

179. The late Mr. Boulton of Soho, was, I believe, the first who used steam for heating the water for a warm bath, which I am told, gave rise to the method of heating the vats, &c. of the dye-house of Messrs. Wormauld & Gott of Leeds.

At Helensburgh, the water for the warm baths is, as usual, heated in a boiler, and admitted as it is wanted. Steam from the same boiler, serves also to heat the bath-rooms, to each of which it is communicated by a small pipe, to a vertical tube of tin-plate about 7 inches diameter, and 4 feet long.

I shall not at present enter into the details of heating *water* by steam, as that subject may furnish matter for a separate Essay.

General Explanation of Plate 2.

Fig. 1, represents the method of connecting pipes by means of *flanches*, (Art. 153).

Fig. 2, *spigot and faucet joint*, (Art. 154).

Fig. 3, *thimble joint*, (Art. 155).

Fig. 4, a method of connecting *spigot and faucet* pipes, where they are to have a round turn or an angle, (Art. 156).

Fig. 5, *saddle joint*, (Art. 157).

Fig. 6, *slipping joint* to allow the pipes to expand, (Art. 159).

Fig. 7, methods of making joints on vertical pipes supporting floors, (Art. 160).

Fig. 8, steam boiler with apparatus for feeding, &c. (Art. 162).

Fig. 9, represents the mode of allowing the air to escape by a pipe at the termination of the steam pipes, and of taking off the *water of condensation* by means of a syphon, (Art. 168).

END OF PART SECOND.

Part Third.

ON

DRYING,

AND

HEATING,

BY STEAM.

INTRODUCTION.

HITHERTO, we have considered those cases only where the temperature does not exceed 70° or 80° of Fahrenheit's thermometer, and where heat only is required; but there is another application of steam, of which we come now to treat, I allude to its use, as a substitute for DRYING-STOVES.

Steam was many years ago tried at Leeds for that purpose; but, for reasons with which I am unacquainted, the plan was abandoned.

A method of drying certain kinds of muslins, by wrapping them round cylinders of tin-plate, has, for several years, been successfully practised by bleachers, in the vicinity of Glasgow. The first idea of them, I believe was suggested by Mr. John Burns of Paisley, in conversation with Mr. Laird, and Mr. Tennant, now of Glasgow. It was first put in practice by the last mentioned gentleman, at the Darnly bleaching works, about the year 1793, about twelve months before it was adopted at any other work. A description of this method of drying muslins, may be seen in "Dr. Ree's Cyclopedia" article, "BLEACHING." Steam-rollers have also been successfully used by calico-printers, for drying their goods; but somewhat different in their modification, from those above alluded to.

181. Mr. Lounds of Paisley, I believe, was the first who succeeded in using steam as a substitute for a drying-stove to dry goods, stretched on frames. This he has done these several years, for the finer kinds of muslins.

The temperature required for such goods, however, is much lower than that required for drying the thicker kinds of cotton-cloth, such as chequered handkerchiefs, called pullicates. Messrs. Muir, Brown, & Co. at Glasgow, were the first who succeeded in the application of steam, for this purpose, and also for drying dyed and bleached yarns, where the temperature required is still higher. They made the first trial of their drying-rooms on March 26th, 1808.

Mr. Muir informs me, that though they formerly gave out their pullicates to be bleached, by some of the best bleachers in this part of the country, that they never had the colours of their goods in the same perfection which they now have, and which improvement they attribute entirely to the superior effect of the steam, and that the more experience he has, he is the more convinced of this advantage from the steam-heat.

I apprehend the superior effect, with regard to colour, of this mode of drying, arises from the difficulty of raising steam-heat to such a degree as to be injurious; as well that no gas which can be hurtful to the colours, is emitted from the steam-pipe. In drying-stoves, on the contrary, the heat is often raised too suddenly to a very high temperature, which gives a harsh feel to the goods; and in such stoves, the air is often much injured by gas emitted from the coackle and the flues, which must certainly have a great influence on the colour of the goods.*

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* A gentleman extensively engaged in calico-printing, favours me with the following note:

"In confirmation of the above, I suppose the superiority of the colours in the drying of the pullicates, and also in the operations of calico-printing, called *padding*, arises from the facility with which steam-heat may be gently and equably applied. By its being so easily regulated to the degrees of the thermometer, it possesses evidently a more convenient applicability to manufacture, where the quality of the commodities depends on the degree of heat, than the other modes."

Mr. Muir gives me the following further information, which must be agreeable to every friend to humanity, that the people who now work in his drying-rooms, were formerly employed in working in a stove heated in the common way, at which time, they had a very emaciated unhealthy appearance; but since they have been employed in the rooms heated by steam, they have become healthy, and their aspect has changed most materially for the better.

182. About this period, Mr. Richard Gillespie, of Anderston, notwithstanding the prejudices of other calico-printers, who predicted that the heat proceeding from steam-pipes, was not of a kind that would

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Since this sheet went to press, Mr. Muir made the following experiment, which seems to prove that it is the *gas*, only, in common stoves, which injures the colour. He took a hank of scarlet yarn and divided it into three parts. Two of these parts were then wetted. One of the wet parts was put into a common drying-stove at 128° of Fahrenheit. The other he laid on a steam-pipe, which raised the thermometer to 165°. When dry, the three parts were compared. The colour of that which was in the stove was much injured, while that which was on the steam-pipe retained the same shade and lustre with the part which had not been wetted. Lilac, purple, pink, and other more delicate colours, would have been much more injured than scarlet.

ever answer in the practice of calico-printing. They required, they said, a *dry heat*, which they conceived could never proceed from steam, a fluid moist in its own nature, forgetting that heat is not altered by being combined with other kinds of matter, and, that in passing through the pipes, if properly executed, the heat must leave the moisture behind. Mr. Gillespie, notwithstanding those prejudices, made the attempt first, in his copper-plate house, and succeeded to his most sanguine wish. His success in this instance, prompted him to apply steam to his block-printing shops, also in which, he has been equally successful.

Previously to these applications, besides heating his warehouse, he had applied it to the heating of his calenders. For which purpose, the steam is conveyed about 93 yards under ground *.

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* I believe the late Mr. John Miller of Glasgow, was the first who applied steam to the heating of a calender, which he did in the month of July 1805.

This mode of heating calenders by steam, is found a very great improvement, not only as it saves time, but improves the appearance of the goods. When heated with red-hot iron heaters, the goods had comparatively a harsh impoverished, dry, brittle feel.

Messrs. Leys, Mason & Co. of Aberdeen, also about this time applied steam (on principles similar to Messrs. Muir, Brown, & Co.) to the purpose of drying cloth at their bleaching works.

SECTION I.

CASE I.—*Drying-House.*

183. CONSISTS of a room 8 feet high, of an irregular figure, containing about 9472 cubic feet of space, and is heated by means of horizontal steam-tubes of tin-plate, about 2 feet from the floor. These tubes are arranged in two separate groups, so as to be immediately under two frames, on which the goods are stretched.

Cubic feet of space, - - - - - - - - - - - - - - - 9472.
Surface of tube, - - - - - - - - - - - - - - - - - - 581.1 feet.
Space heated by one foot surface of tin-tube, 16.2 cub. feet.

But as cast-iron emits 2½ times more heat than tin-plate, (Art. 140.) the less tube would have served, in which case, the space heated by one foot surface, would be represented by 2½ times 16. That is, 40 cubic feet of space heated by 1 superficial foot of cast-iron, temperature 90°.

Observations.

In summer, this room is sometimes at 100°; in winter, generally 90°.

On the 18th of November, 1808, it was only 80°, the external air at the time being 42°, being a difference of 38 between the external and internal air.

The goods dried here, are thin muslins, stretched on frames, the air being agitated by a pendulous fan.

It is employed first, strictly as a heating stove, and the windows kept all close shut, until the vapour from the goods begins to condense on the windows. As soon as the steam begins to obscure the glass, the attendants open them to let off the vapour, and when that is done, they shut them again; thus alternately heating and ventilating.

This mode appears to me exceedingly judicious; formerly, there was no persuasion could make operatives see the propriety of ventilation in a drying-stove.

They now find that ventilation is necessary to a certain degree, which degree Mr. Dalton (in his Letter of 14th June, 1808,) says, "has not yet, I conceive, been determined." *Query*, Whether may not the appearances on the glass, now mentioned, serve as some indication of the degree? A hygrometer might, probably, be of very great use in situations of this kind. (Art. 82.)

One of the most scientific and experienced bleachers we have, informed me, (April, 1806,) that stoves were much improved, by admitting a more free circulation of air, and, in that case, 80°, or even 70°, was sufficient for purposes which required 100°, in a close house.

It is evident, that the heat operates on the cloth, by evaporating the water, but after it has thus suspended the moisture, if it be not allowed to escape somewhere, it must remain in the room, and retard the process. In other words, it is keeping the goods in a damp, although warm, atmosphere.

CASE II.—*Drying-House.*

184. This drying-house is heated by horizontal cast-iron steam-tubes, in such proportion, that one foot surface, heats about 80 cubic feet of space.

The steam is kept in the tubes in the night, as well as in the day.

The temperature in November 1807, was 100°.

CASE III.—*Drying-Rooms.*

185. In this case, there are two rooms for drying by steam, the one for cloth, and the other for yarn.

These rooms are both on the same floor, one story above ground. The steam is generated in a boiler, which supplies a steam-engine and other purposes. That for the yarn, requires to be considerably hotter than that for the goods.

The whole of these steam-tubes are of cast-iron, eight inches external diameter, and are joined by *thimbles* where they are straight, by *saddle joints* at the branches, and by *spigot and faucet joints* at the angles. (See Art. 154—157.)

The most of the joints are made with iron cement (Art. 158). Lead was tried for some of them, but was found not to make a lasting joint.

The tubes are placed near the floor, inclining downwards as they recede from the boiler. In order to allow them to move freely in expanding and contracting, they are supported by hollow cast-iron rollers, which rest on blocks of wood, rounded in a contrary direction on their under side, which rests on the floor. Thus forming a kind of universal joint.

Where the steam-tubes come in contact with the walls of the building, pieces of tin-plate are interposed, in order to save the heat. (See Art. 90 and 144.)

The rooms are both eight feet high. The yarn-room contains 4,224 cubic feet of space.

Cubic feet of space heated by 1 superficial foot of steam-pipe, $16\frac{16}{65}$.

Cloth room contains 5,952 cubic feet.

Cubic feet of space heated by 1 superficial foot of steam-pipe, $23\frac{13}{42}$.

There is a valve, where the steam-conductor branches off from the boiler, laden just to that degree, that when the steam becomes weak, it shuts, and allows the whole of it to go to supply the steam-engine.

Observations.

These rooms were first tried on the 26th March, 1808; the walls were then damp, from having been recently plaistered.

The external air was - - - - - 42°.
The cloth-room - - - - - - - - - 91°.
The yarn-room - - - - - - - - - 99°.

The steam boiler is only kept boiling during the day, and is rather small to supply the various purposes to which it is applied, so that the rooms are not kept nearly so hot as otherwise they might be. There are also several of the panes of glass broken, and often a great deal of wet goods in the rooms; but, notwithstanding those disadvantages, the temperature is generally from 86° to 96°. The yarn room is commonly about 10° higher than that for cloth. The former, in summer, was often as hot as 120°.

Notwithstanding the lowness of the temperature, these two rooms dry as much goods, and with as few hands, as any stoves of the same dimensions, even where the temperature is much higher. And it is pleasing to reflect, that the people working in the steam rooms, are much more healthy and comfortable, than those in the contaminated air proceeding from stoves, as commonly constructed for such purposes.

The proprietors assure me, that they are more and more convinced of the superior effects of steam, with respect to the colour and finish of the goods, as well as with the much greater economy of the process; and, that they are so much convinced of the superior colour and finish, that although it *were at double the expense of stove heat*, they would still use it in preference.

On the 14th of January, 1809, the temperature of the external air being 29°,

The cloth room was - - - - 86°.
The yarn room was - - - - 101°.

Although the windows were partly open, and a great deal of wet goods in the rooms.

The attendants find here, that the advantage of a circulation of air, depends very much upon the state of the weather. When it is damp, they find it is best to keep the windows shut, and to raise the steam heat; but, on the contrary, when the weather is dry, a free circulation of air is of much greater consequence than a high temperature.

CASE IV.—*Calico Printing.*

186. The steam is generated in a boiler of about twenty horses' power, which supplies a steam-engine of ten horses' power. The steam is conveyed about ninety-three yards under ground, to heat two calenders, and warm counting-houses and warehouses. It also heats the copper-plate house, block-printing shops, and heats water for the processes of branning, dyeing, &c.

1. *Copper-Plate House.*

The copper-plate presses are driven by the steam-engine, and stand in a room one story above the ground.

About six inches from the ceiling, is a horizontal steam-tube, six inches external diameter.

The garret above the presses, is occupied for drying the cloth, as it passes from the presses; which arrangement allows the printers to work in a moderate temperature, while the goods are drying in a temperature much higher. The garret is heated partly from the heat which rises from the press-room, and partly from a horizontal tube, seven inches external diameter.

But, as there is a communication between the rooms, they ought to be taken together. Therefore, press-room and garret taken together, the space heated by 1 foot surface of steam-tube is 181 cubic feet.

On the 12th February, 1808, the temperature of the external air, early in the morning, was 27°, about eleven o'clock, it was 30°.

The press-room - - - - - - - - 64°.
The garret - - - - - - - - - - 73°.

Notwithstanding the coldness of the external air, the cloth from the presses was made, to use the overseer's expression, *bone dry*, and the operations going on to the complete satisfaction of the proprietors.

12th of March, 1808, the thermometer in the garret, stood at 105°.

2. *Block-Printing Shops.*

The block-printing shops are each heated by a horizontal steam-tube, 11¼ inches diameter, of cast-iron, about 2½ feet from each floor; and the temperature, when there is a sufficiency of steam, is usually about 80°.

Here 90 cubic feet is the space heated by one foot surface of steam-tube.

Observations.

This mode of heating for this kind of printing, gives equal satisfaction with that for the copper-plate department.

It is proper to have a boiler of sufficient capacity, in order that the steam may be used for all the various purposes to which it is applicable, in the different processes in calico-printing. In this particular case, the proprietor informs me, that since he has used steam as a substitute for stoves, &c. the saving produced has been very great.

SECTION II.

Of the difference of Temperature between the external Air and the internal Air of a Building heated by Steam.

187. HOPING that it might be satisfactory to many, to know whether the difference of temperature between the external and the internal air of a building heated by steam, was nearly *constant*, and conceiving, that it might lead to some useful inference, I was induced to have the subject experimentally examined. This examination Mr. H. Houldsworth had the goodness to permit me to make at one of his mills in Anderston; the result of which is given in the following table.

From the table, it will appear that the difference is far from being constant, and that it is greatest when the air is coldest.

Table of the state of the Thermometer in the open Air, and in a Cotton-Mill, the property of H. Houldsworth, Esq. each day at 12 *o'clock.*

Date.	1806	Open Air.	Mill	Dif.	Date.	1808	Open Air.	Mill.	Dif.
February.	12	26°	76°	50°	April.	1	37°	82°	45°
——	13	28	78	50	——	2	42	83	41
——	15	44	74	30	——	4	49	80	31
——	16	42	80	38	——	5	48	82	34
——	17	42	82	40	——	6	46	84	38
——	18	52	61	9	——	7	50	84	34
——	19	48	82	34	——	8	48	84	36
——	20	43	82	39	——	9	53	84	31
——	22	39	77	38	——	11	56	83	27
——	23	38	81	43	——	12	58	84	26
——	24	34	78	44	——	13	59	84	25
——	25	36	74	88	——	14	53	84	31
——	26	46	79	33	——	15	56	84	28
——	27	50	60	30	——	16	55	83	28
——	29	48	78	30	——	18	39	84	45
March.	1	50	82	32	— —	19	42	85	43
——	2	50	80	30	——	20	49	84	35
——	3	54	82	28	——	21	48	85	37
——	4	48	74	26	——	22	46	85	39
——	5	42	80	38	——	23	45	85	40
——	7	44	76	32	——	25	47	79	32
——	8	42	82	40	——	26	48	84	36
——	9	46	82	36	——	27	50	84	34
——	10	46	62	36	——	26	52	85	33
——	11	46	82	36	——	29	48	65	37
——	12	44	84	40	——	30	51	86	35
——	14	42	77	35	May.	2	58	86	28
——	15	44	83	39	——	3	64	86	22
——	16	47	84	37	——	4	65	85	20
——	17	42	82	40	——	5	72	86	14
——	18	40	79	39	——	6	62	86	24
——	19	38	78	40	——	7	63	85	22
——	21	36	80	44	——	9	59	62	23
——	22	39	82	43	——	10	56	79	23
——	23	40	82	42	——	11	62	86	24
——	24	40	82	42	——	12	60	86	26
——	25	37	84	47	——	13	62	86	24
——	26	42	82	40	——	14	64	66	22
——	28	42	80	33					
——	29	42	82	40					
——	30	40	83	43					
——	31	43	82	39					

SECTION III.

Of the proportion between the Surface of Steam-Pipe, and the Heat produced.

188. It is of considerable practical importance, to be able to calculate the quantity of steam-pipe which will be necessary to produce a given temperature. It must be confessed, however, that such an estimate admits not of absolute precision.

The temperature will, obviously, not increase in a ratio nearly so high as the increase of surface of pipe. For, suppose a room already at 70°, and that, by means of a cock or valve, we suddenly introduce steam into another tube, which is equal to that already producing the 70°, the difference of temperature between the external and internal surfaces of the second pipe, is much less than it was in the first. Of course, the condensation must go on much more slowly, and were the air at 112°, and the steam of the same density as the atmosphere, no condensation at all could take place. The facts which are collected in the annexed table, will, however, enable the practical reader to approximate toward the truth; and he will there see, perhaps, nearly the maximum temperature which is to be expected in any case in practice, where the rooms have but little ventilation. Where the ventilation is great, it follows, that the effect of the surface of steam-tubes must be lessened. In this table, I would beg leave to direct the reader's attention to the difference between the temperature of the external and internal air, as being likely to furnish a guide in calculating the quantity of pipe requisite in any given case.

In order to form some idea of the greatest heat which could probably be expected from steam-tubes, when the surface should be very great, I made the following experiments, which were repeated, with nearly the same results. These results are, for the sake of bringing the whole of this part of the subject into one view, given in the table.

Experiment 1*st.*

189. A cylindrical tin-plate canister, two inches diameter, and five inches long, with a small projecting rim at one end, to receive a cork. A Fahrenheit's thermometer was inserted through the cork, so that its bulb was nearly in the centre of the canister. It may be proper to remark, that the tin-plate was become dim, from having been long exposed to the air.

This canister was plunged its whole depth into boiling water. The thermometer, which previously stood at 60°, rose to 160°. The barometer stood at 29.5.

Observations.

In this and the following experiments, upon emersing the canisters into the boiling water, part of the air which was expanded by the heat, escaped between the cork and the thermometer. But this is what must occur in practice on the great scale, as the rarified air must escape from an apartment, when it becomes heated.

The contents of the canister was 0.00909 cubic feet.

The surface exposed to the hot water, 0.2563 superficial feet.

Space heated proportionate to one superficial foot of surface exposed to the hot water, 0.035466.

Experiment 2d.

190. The same canister, coated in the inside with lamp black and size, all other circumstances being as in the first experiment, was immersed its whole depth in boiling water. The thermometer rose to 190°.

Observations.

Here we see the increase of effect 30 degrees, occasioned by coating the surface of the tin-plate with lamp black. (See Art. 83.)

Experiment 3d.

191. The canister, all other circumstances as in experiment 2d, was half im-

mersed in boiling water. The thermometer rose to 176°.

Observations.

The space heated proportionate to one superficial foot of surface exposed to the hot water, which, in this case, was double that of experiment 2d, or 0.070932, which alteration lowered the thermometer 24°.

Experiment 4th.

192. A small canister of tin-plate, of an elliptical form, about 2.75 inches deep, having its greatest diameter 1.9 inches, and its least 0.8. The tin-plate, as in the cylindrical canister, was tarnished. A thermometer was also inserted through a cork. The canister being immersed into boiling water, the thermometer rose to 190 .

Experiment 5th.

193. The 4th experiment repeated, with this difference only, viz. that the inside of the canister was coated with lamp black. The thermometer rose no higher than 190°.

Observations on Experiments 4th and 5th.

In the 4th and 5th experiments, the contents of the canister was 0.001899 cubic feet.

Surface exposed to the hot water, 0.107291 superficial feet.

Space heated proportionate to one superficial foot of surface exposed to the hot water, .017699.

In so small a space, compared with the surface, coating appears to have no influence on the projecting power, for the result, 190°, in both these experiments, is the same.

We may infer from Experiments 3d, 4th, and 5th, that *the maximum heat to be produced by steam, where the air is not confined, is* 190 *degrees.*

194. *Table showing the Heat produced from different Proportions of Steam-Pipe.*

	Cubic feet warmed by 1 super. foot of steam-pipe.	External Air.	Internal Air.	Difference of temperature.
Chapel at Port-Glasgow,	400	40	60	20
Cotton-Mills, - - -	200	34	70	36
Case I. (Art. 183.) -	40	34	90	56
Case II. (Art. 184.) -	80	34	100	66
Case III. (Art. 185.) cloth-room, - - -	23	42	91	49
		29	86	55
Do. yarn-room, - - -	16	42	99	57
		29	101	72
Experiment 2d, (Art. 190.) - - - - -	0.035466	60	190	130
Experiment 3d, (Art. 190.) - - - - -	0.070932	60	176	116

Observations on the Table.

The 2d and 3d experiments only, are inserted because the 2d shows the *maximum heat*, (Art. 193,) and the 3d, the alteration of temperature occasioned by heating double the space by the same surface. All the cases in the table have the surface, either coated, or, what is equivalent, of cast-iron, (Art. 142).

SECTION IV.

Miscellaneous Observations.

195. ATTEMPTS have been made, to bring a current of air over steam-pipes, or through pipes included in others, filled with steam, in order, by quickening the condensation, to make a less surface of steam-pipe heat an equal space. Mr. Roberton tried this plan, by enclosing the pipes in trunks, and producing a current, by the rarefaction of the air*. I have attempted the same thing, by increasing the current of air by machinery, but I cannot

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* These trials were made with pipes of tin-plate, included in wooden trunks, at one end of the rooms. The air entered the trunk at the floor, and escaped at the ceiling. Mr. Roberton found that the heat was, to a certain degree, increased by this circulation, and that the temperature, at the further end of a room of great extent, was nearly equal to what it was near the trunk. From the pipes being made of tin-plate, however, they required frequent repair, which rendered the wooden trunks about them inconvenient, and for that reason they were removed. Had it not been from this circumstance, he is of opinion, that considerable advantage would have been derived from the trunks, and would recommend them for cast-iron pipes, which would not require the frequent repair necessary, where the pipes were made of tin-plate.

say, that much practical advantage has resulted from these trials, (see Note C.) We saw, however, (Art. 178.) that Mr. Lee had successfully employed the principle of rarefaction, in heating part of his dwelling-house, and it is probable, that this principle will be more generally applied.

It has been proposed by some, to heat the external air, and throw it into the apartments, in a manner similar to some kinds of stoves, supposing, that thus by *combining ventilation with heating*, it would be more salubrious. But this would be obtaining heat at a great expense of fuel, and be losing one very important advantage which attends heating by steam, viz. that the heating may be *kept perfectly separate* from the ventilating process, so that each may be managed separately, and no more heat nor ventilation given than what is just proper. Whereas, on the other plan, there must always be nearly the same ventilation, whether the external air be dry or damp, warm or cold. When damp, a great quantity of moisture must be thrown into the building, which will require additional heat to suspend it, in order to prevent it from being injurious, and when the air is dry, the current of air will carry in dust along with it. I would, therefore, recommend producing the *current* from the *rarefaction of the air within the building*, and ventilating by the window, or other proper openings for the purpose.

Mr. Houldsworth found, that the maximum heat to be produced by the rarefaction, was about 140 degrees.

196. Some have apprehended, that heating by steam might be inconvenient, on account of the very great heat which would be felt for some feet round the pipes; but this is not the fact, for even when they are not included in any kind of air-trunk, as soon as a particle of air becomes heated, being specifically lighter, it has a tendency to ascend to the ceiling of the apartment. The warm air first accumulates there, and

gradually descending, as is often visible in a room, when warm air enters, mingled with smoke. The cloud first appears along the ceiling, and then gradually descends, keeping nearly a uniform surface below.

That no inconvenience arises in practice, we have a full proof, in the case of an extensive cotton-mill in Manchester, (see Art. 173.) which is 42 feet wide. The steam-pipes go along the floor on *one side only*, and although the yarn spun in this mill be remarkably fine, no difference of temperature is experienced, which, in the smallest degree, affects that delicate process.

197. When speaking of *spigot and faucet joints*, (Art. 154.) I omitted to mention, that it seems a good method to cast the faucets thin, and to hoop them with slight wrought-iron, put on at a low red heat. The thinness makes the faucets expand along with the spigot, while the hoop gives strength, to allow the cement to be firmly driven into the joint.

198. In Art. 166, it is mentioned, that a glass tube is sometimes used, to show the height of the water in the boiler. This simple contrivance, is, by some, applied for the further very important purposes of measuring the heat produced by the fuel employed in a given time, and showing the quantity of steam used. Great advantage may arise from ascertaining these points. Thus, one kind of fuel may be compared with another. Using the same fuel, it will show the comparative effects of different states of the furnace, and different modes of treatment. It also shows accurately, the quantity of steam which a steam-engine is using, according to the order in which it is kept. It may, therefore, be proper to give a more detailed explanation of the mode of using this ingenious contrivance.

The most simple and accurate mode of comparing one kind of fuel with another, is, to measure the quantity of water which, under the same circumstances, equal weights of each will evaporate, (see Articles 45, 52—70, and 111.) Now, by having a scale attached to the glass tube, and knowing the dimensions of the boiler, opposite each of the divisions on the scale, it becomes easy to form a table, which will readily show the number of cubic feet or inches, to which each division of the scale is equal.

At the most convenient time of each day, (which in many manufactories will be the dinner hour,) put as much extra water into the boiler, as will allow it to boil for two hours, without getting any supply of water whatever. This being done, let every thing, excepting the feeding apparatus of the boiler, be set to work as usual for two hours. The scale will indicate the cubic feet of water, which, during that period, has been evaporated; a register of which may be kept, from which many useful practical inferences may be drawn.

The tube should be a common barrometer tube, of a pretty large bore, and the thinner it is, it will be the less liable to break from unequal expansion.

199. Care should be taken, to have all the pipes about the boiler sufficiently large, to insure the prompt action of the feeding-apparatus, and to prevent them from the risk of choaking, by any extraneous matter which may be in the boiler.

200. The pipes also, which are to communicate steam to a distance, should be made sufficiently large, the sooner to fill the more distant parts of the apparatus. When the pipes are small, the surface being great in proportion to the contained steam, the condensation goes on very rapidly, and retards the progress of the steam.

201. In situations where heat is not wanted from the conducting pipes, it will be proper to defend them from the atmosphere. This may be efficaciously done, by enclosing them within tubes of tin-plate, leaving a space all round, of about

an inch between the steam-pipe and the tin-tube, (see Articles 90—96, and 144).

But should this mode be thought too expensive, a cheaper method may be adopted, that of wrapping the steam-pipes round with a considerable thickness of straw ropes, putting a coating over them of fine plaister-lime, and, after it is dry, washing them over with lime-water, in order to fill up any little cracks which may appear.

202. Where there is found from experience, to be too much heat in one place of a building, and too little in another, tin-tubes, as above described, may be used, allowing a current of air to pass between them and the steam-pipes, which heated air may be conveyed to any higher situation, by means of a pipe of tin-plate.

These covers may be made capable of increase or diminution, by various contrivances, such, for instance, as forming them on the principles of a sliding spy-glass, as is done in the counting-room of the printing-house of Messrs. James Ballantyne & Co. Edinburgh.

Brick-work, in some cases, may be used for enclosing steam-pipes, instead of the tin-plate.

203. A great saving of fuel may be obtained, by using double sashes in the windows, a practice common on some parts of the Continent.

204. We saw, (Art. 174 and 176.) that it requires a considerable time, where there is a great length of steam-pipes, to expel the air from them, and to fill them with steam. To obviate this inconvenience, Mr. H. Houldsworth proposed a plan, of applying a pump to the pipes, worked by a steam-engine. First, to expel the air, which would allow the steam speedily to fill the pipes. Afterwards, it would serve the purpose of forcing back the *water of condensation* to the boiler, which would produce some saving of fuel; for it, at present,

escapes nearly at the boiling-point, while the boiler is supplied with water from the air-pump of the steam-engine, about 100 degrees colder. Mr. Houldsworth's plan would be attended with a further saving of fuel, for, by the common mode, a uniform heat cannot be maintained, unless there be a constant discharge of a small quantity of steam from the extremity of the pipes, (Art. 168.) but the forcing-pump, by occasioning a constant circulation of steam in the pipes, would ensure a uniform heat, without any loss of steam. This plan has not yet, however, been brought to the test of experience.

205. The *water of condensation*, being *distilled water*, it may often be of use to collect it for washing or other purposes, for which soft pure water is desireable.

206. There is considerable difficulty in obtaining accurate data, to compare the *expense of fuel*, in heating by steam with other modes. From the best information, however, that I could obtain, I made cal-

culations on the supposition, that the steam was supplied from a large boiler, and the rest employed for driving a steam-engine, or for some other useful purpose. On this principle then, it appeared, in general, that open fires require considerably more fuel to heat the same space, than steam. Stoves, as commonly constructed and used in our cotton-mills, seem also to require more fuel than steam. With regard to the improved stoves, which are now only beginning to be used in some manufactories, I do not know, that any accurate comparison has yet been made.

207. In most manufactories, there is a great many separate fires, which occasion, in proportion to their number, not only a loss of heat from the fuel consumed, but also of waste from inattention and carelessness; where steam, therefore, can be used as a substitute for these, a great saving of fuel will accrue.

208. Although in situations in which there is a steam-engine, or a regular sup-

ply of steam kept up for other purposes, it may be proper to use steam for warming buildings; yet, where that is not the case, unless a person can be appropriated to the sole purpose of attending on the boiler, I would hesitate to recommend it; for the trouble and expense of attending on a small boiler, on the common construction, and risk from carelessness of not keeping up a regular heat, or of having it burst or burnt out, would more than counterbalance the advantage otherwise to be derived from it. But I am much pleased to find that ingenious mechanics are turning their attention to the fitting up of boilers, so as to require less attendance *.

209. Steam, however, has many material advantages over every kind of stoves; most kinds of stoves are more or less liable to injure the air, which comes in contact with them, and to consume the dust. A disagreeable oppressive smell is often produced, occasioned, probably, not only from

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* See Mr. M'Naught's Letter, Art. 180.

the combustion of the dust, but also from the decomposition of the water suspended in the atmosphere. The disadvantages of throwing in a current of air, by heating the external air, and combining ventilation with heating, have already been mentioned, (Art. 195,) and to these objections, some of our most improved stoves are liable.

All kinds of stoves are more or less dangerous, and when constructed on the principle of ventilation, they may become particularly so, when the coakle or pan cracks, or is burnt out. In that case, the flames may find their way into the air-flues, and so into the building. The coakles, in many situations, soon fail in some part; in which case, putting the danger out of the question, they must greatly contaminate the air. It has been supposed, that more cotton-mills have been destroyed by fire, occasioned by stoves, than from all other causes put together.

But steam being free from dust, and the atmosphere uninjured by its heat, while it is much more cleanly and safe, it must be more healthful than any kind of stove.

Steam has another advantage over the late improved stoves, that it can easily be extended through buildings which are widely spread, and nearly on the same level; such, for instance, as are very common in calico printing works: whereas from the tendency which heated air has to ascend, it is exceedingly difficult to heat places which are not considerably above the level of the stove.

210. After considering the facts detailed in this Essay, many other purposes than those already mentioned, will suggest themselves to readers, to which heating by steam may be usefully applied. It would require a greater scope of knowledge, than an individual could lay claim to, to point them out *. To some purposes, however,

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* It is worthy the consideration of those acquainted with nautical affairs, how far it may be applicable in ships, particularly in men of war.

there may be considerable obstacles; for instance, it has been often proposed for heating hot-houses; but a difficulty occurs here, of keeping up a regular heat during the night, which could not, with a boiler on the common construction, I believe, in most cases, be done, without increasing the expense of attendants. Were it not for this objection, the heat from steam-pipes appears to be more genial than that from brick flues; and, in this case, perhaps a boiler with a furnace similar to that described in Mr. M'Naught's letter, (Art. 180,) might be found to answer the purpose, without any additional expense of attendance.

But in the progress of improvement, obstacles which at present exist to the use of steam, may be removed. I have endeavoured plainly to state facts as they are at present, and ingenious men may draw conclusions from them, which may contribute to extend the useful application of steam to many purposes, to which it is not at present thought applicable.

NOTES.

Note A.

Messrs. H. Houldsworth & Co. at their old mill, Anderston, have a boiler equal to that commonly used for a steam-engine of twenty-one horse's power.

But their engine has only the power of sixteen horses; there is, therefore, a surplus power of five horses in the boiler, and this is appropriated to the warming of the building; for which purpose it is found quite sufficient.

The building consists of the mill in front, and a house behind, of the same length as the mill; but not so large in its other dimensions.

The mill contains 6 stories, each 116 feet long, by 27 feet 8 inches wide, by 9 feet high, equal to 28,884 cubic feet. Therefore, 28,884 cubic feet multiplied by 6 stories, is equal to 173,304 cubic feet in the mill. The back house contains 76,696 cubic feet; the whole is, therefore, 250,000 cubic feet. Then will 250,000 cubic feet, divided by five horses, be equal to 50,000 cubic feet, the space which a boiler of one horse's power will warm in a cotton-mill.

Now, reckoning that a horse's power occupies 25 cubic feet in a boiler, 50,000 cubic feet of space, divided by 25, is equal to 2,000 cubic feet of space, which may be warmed by 1 cubic foot of boiler.

It may be proper to observe, that this allowance may be considered as perfectly sufficient; for the thermometer in the mill often stands above 80° of Fahrenheit.

In the Linwood cotton-mill, (see Note B,) for every cubic foot of boiler, 2,500 cubic feet of space were warmed up to 70 degrees of Fahrenheit, under the disadvantages of a newly fitted up building, and a large opening for the water-wheel. *So that we may safely reckon upon a horse's power as being fully adequate to warm* 50,000 *cubic* *feet of space. Or, what amounts to the same thing, that one cubic foot of boiler will warm* 2,000 *cubic feet of space.*

Note B.

General abstract relative to several Buildings which have been warmed by Steam.

Name of Mills.	Substance of which the steam-pipes are made.	Cubic feet of space in building.	Cubic feet in boiler.	Space warmed by 1 cubic foot of boiler.	Cubic feet of space warmed by 1 superficial foot of steam pipe	Temperature, degrees of Fahren. in winter.
Messrs. H. Houldsworth & Co. Anderston Old Mill, -	Cast-Iron,	250,000	—	2,000	178	85°
Linwood Do. - - - - -	Cast-Iron,	300,000	120	2,500	168	70
Messrs. Kennedy & Watts, Johnston,	Cast-Iron,	289,000	160	1,180	160	75
Catrine, - - - - - - - -	Tin-Plate not painted,	—	—	—	200	—
Mr. Thomas Houldsworth's Mill, Manchester, - - - - -	Cast-Iron.	—	—	—	195	—
Chapel of Port-Glasgow, - -	Cast-Iron,	60,000	10	6,000	400	—
Part of Adelphi Cotton Works,	Cast-Iron,	49,140	—	—	182	65
Tambouring Mill at Anderston,	Cast-Iron,	—	—	—	240	60
Messrs. William King and Sons, Johnston, - - - - - -	Cast-Iron,	244,583	180	1,303	200	70
Mr. Sym's Mill, Glasgow, - -	Tin-Plate,	100,395	—	—	160	72
Deanston Mill, Doun, - - -	Tin-Plate,	174,720	—	—	—	—
Douglas, Cook, & Co.'s, -	Tin-Plate not painted,	55,296 16,848 65,934	250	552.5	98.6	72
Messrs. Houldsworth & Hussie,	Cast-Iron,	96,798	—	—	165.2	87
Inn at Johnston, - - - - -	—	—	—	—	200	—

NOTE C. (see Art. 195.)

In June 1806, I made the following experiments, in order to try the effect on the temperature of a room, by increasing the current of air over the surface of steam-pipes.

The room was 39 feet long, 22 feet wide, and 9 feet high. It contained a group of steam-pipes of tin-plate in a vertical position, fitted up and enclosed in a wooden trunk, upon Mr. Roberton's plan, (Art. 195). In order to increase the current of air, a pair of fanners were made to suck it out of the upper part of the trunk, and to throw it into the room. The fanners were 18 inches diameter, and 12 inches wide, making 600 revolutions per minute.

Experiment 1st.

	F. Therm.
External air - - - -	61°
Heat of room from steam-pipes, fanners at rest - - - -	71°
Fanners half an hour in motion raised the temperature to - -	76°

After the fanners had been 20 minutes at rest, the temperature fell to	73°
The fanners were put in motion again for 15 minutes, which raised the temperature to - - -	76°
Thermometer held in the stream of air issuing from the fanners, rose to - - - - -	104°

Observations.

The temperature of the room before the steam was admitted into the pipes, was omitted to be noted, but the difference between the external temperature and that of the room, was, at the beginning of the experiment, 10°. The motion of the fanners, increased the temperature 5° more.

Experiment 2d.

	F. Therm.
External air, - - - -	63°
Heat of the room before admitting the steam into the pipes, -	70
Steam in the pipes for an hour, but the fanners at rest, raised the temperature to - - - -	74°

Fanners in motion for half an hour, raised the temperature to -	76°
Thermometer held in the stream of air issuing from the fanners, rose to - - - - -	125

Observations.

In experiment 2d, the temperature of the room, previously to admitting the steam into the pipes, was 7° higher than the external air. The steam raised it in an hour 4° more, and the fanners 2° higher.

Hence the fanners appear to have increased the effect of the steam-pipes one-half, but it must be confessed, that it would require a more extensive and accurate set of experiments, in order to draw satisfactory inferences. In the mean time, however, I hope the above facts may not be without their value.

ADDITIONS AND CORRECTIONS.

Art. 14—25. I find, that some of our most eminent chemists, are not yet convinced of the accuracy of Mr. Dalton's speculations, with regard to the law of the expansion of liquids, and its influence on the construction of the thermometer; nor are they disposed to admit the alteration in the thermometric scale, which Mr. Dalton proposes.

Art. 58. Since this article was printed off, I have had an opportunity of reading "Speeches of H. Brougham, before the committee of the House of Commons, in opposition to the gas-light and coke company." Mr. Brougham there states many curious and important facts, two of which it will not be improper here to mention. 1st, *That six pounds of coal produces light equal to one pound of tallow.* 2d, That the London Fire Company offered to insure the works of Messrs. Philips & Lee, after they were lighted by the coal gas, at *one half the former premium.*

Art. 67. There has never, I believe, been any very *accurate* comparison of Glasgow coal with that of Newcastle. Some are of opinion, that it requires about *double* the quantity of Glasgow coal to produce the same heat as that of Newcastle.

Art. 68. From the nature of the thing, culm must differ much in its effects in producing heat. Therefore, we may expect some results very different from that stated in this article.

Art. 154. It is a good method to make the *faucets* with an inner part, no larger in diameter than just to fit the *spigot*. This supports the pipe, independently of the cement, and prevents the risk of hurting the joint from any external stress. This inner faucet is commonly made about two inches deep, and has the spigot inserted one inch into it. The practice of some, is to make the outer faucet, or that which contains the cement, six inches deep, for all pipes above six inches diameter; and to make the faucets of all pipes below six inches, the same depth as the diameter of the pipes.

It is usual to make the space for the cement, all round the spigot, from ⅜ to ½ an inch; that width is required, in order that the cement may be firmly driven into the joint. When the space is very narrow, this cannot be done. On the other hand, when too wide, there is a waste of cement, and a risk of injury from unequal expansion.

Page 63, line 22, *for* wood, charcoal, *read* wood-charcoal.
—— 173, last line, *for* Belidores Arch. Hydraulique, *read* Architecture Hydraulique, par M. Belidore, tom. iii.
—— 158, *for* Reaumeur, *read* Reaumur.
—— 174, line 4, 7, 9, and 11, *for* facet *read* faucet.
—— 175, — 5 and 16, *for* facet *read* faucet.
—— 181, — 19, *for* the valve a, *read* the valve e.
—— 182, — 4, 5, and 14, *for* guage-cock *read* gauge-cock.
—— 192, — 15, *for* new *read* next.
—— 223, — 22, *for* 112 *read* 212.

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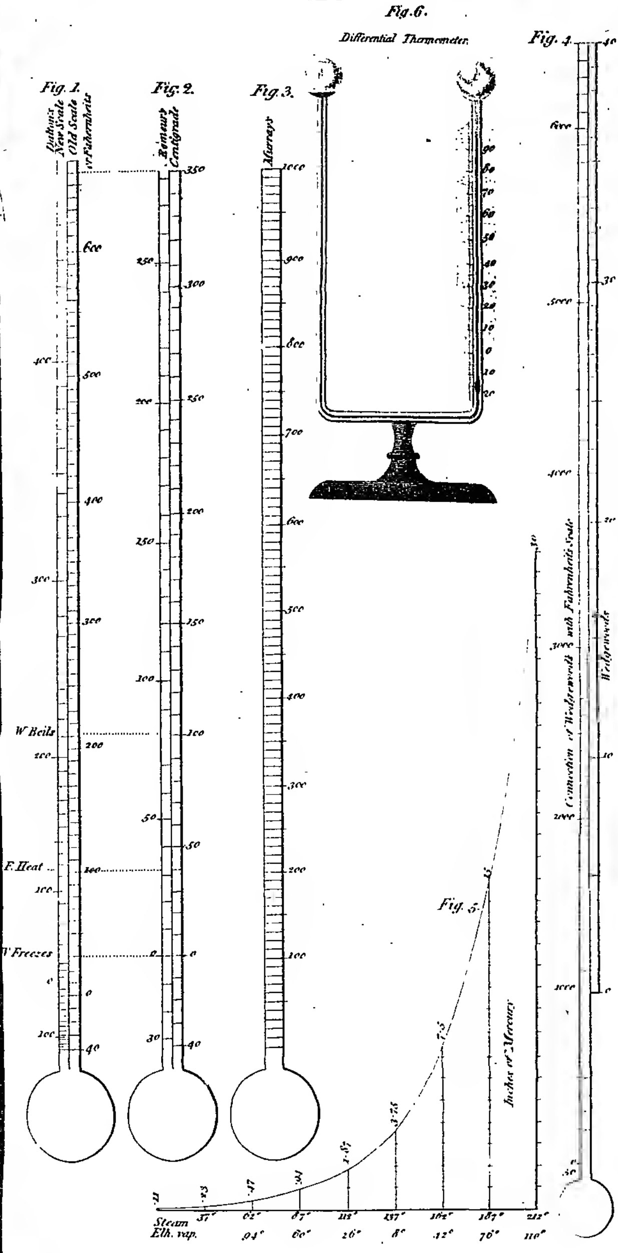

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PLATE 2nd

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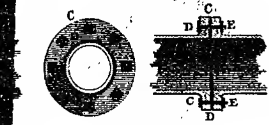

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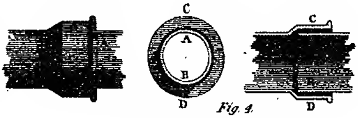

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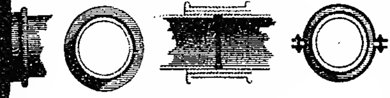

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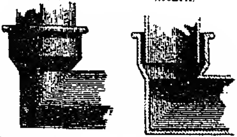

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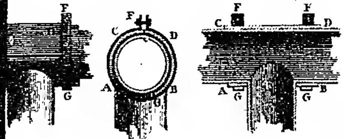


Fig. 4. No 3. Profile.

Fig. 6. Longitudinal Section.

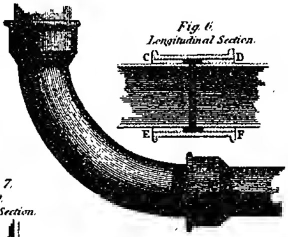


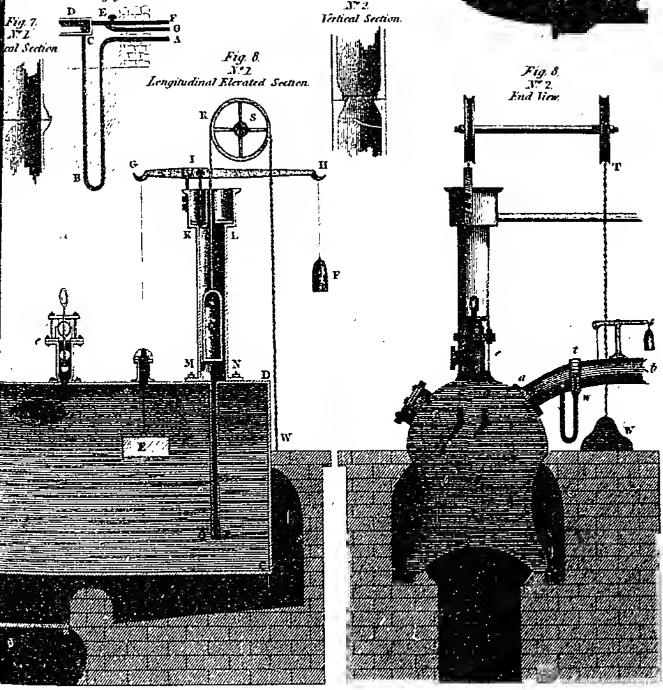
Fig. 7. No 1. …al Section

Fig. 9.

Fig. 7. No 2. Vertical Section.

Fig. 8. No 1. Longitudinal Elevated Section.

Fig. 8. No 2. End View.



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